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(54) Combustion of organic wastes

(57) Method and systems for burning organic wastes such as scrap tires and waste plastics for various purposes including gasification and production of carbon black. In one aspect, a process and system for producing carbon black is disclosed. Also, the use of steam together with air or oxygen-containing gas is disclosed for combustion and/or gasification processes for scrap tires and other organic matters including plastics in fixed-bed furnaces.

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Description**BACKGROUND OF THE INVENTION**5 **1. Field of the Invention**

The present invention generally relates to combustion of organic wastes, such as scrap tires and waste plastics. More specifically, in a first aspect, the invention relates to a method for producing carbon black using scrap tires and other organic waste, such as waste plastics, as raw material, and to systems for carrying out these processes. In a second aspect, the invention relates to a method for the combustion of organic waste which makes it possible to achieve smooth combustion without forming soot and tar or leaving unburned fixed carbon and also to recover energy by steam generation or the like. In third to sixth aspects, to a fixed-bed gasification furnace for gasifying organic waste such as scrap tires and waste plastics and also for producing carbon black, and a method for gasifying organic waste or for producing carbon black from such waste by using such a furnace.

15 **2. Description of the Related Art**

Conventionally, organic waste such as scrap tires and waste plastics has been directly incinerated only for the purpose of generating steam by means of a heat exchanger and utilizing the steam as a heat source. Thus, such organic waste has not practically been used as an ingredient or resource for other products.

When scrap tires are taken as an example of organic waste, they are composed of 50-60% of volatiles, 20-30% of fixed carbon, and 10-15% of inorganic matter such as steel and ash, as shown in Table 1. Since scrap tires include steel wires, it is difficult to crush them into small pieces. Accordingly, it has been conventional practice to burn whole scrap tires in a stoker or kiln or to crush scrap tires to about 10 cm cubes and burn them in a stoker or kiln. However, these combustion methods involve the following problems:

- (1) If scrap tires are burned with the aid of air, volatiles present therein decompose and burn rapidly. As a result, a high temperature of 1,500°C or above is attained locally, tending to cause damage to the furnace. Moreover, large amounts of soot and tar are produced from the flame, requiring after-treatment.
- 30 (2) Fixed carbon has such a low burning rate that it may form a residue in admixture with inorganic matter. This residue is not easy to dispose of.

For these reasons, it is difficult to dispose of organic waste such as scrap tires. In the present state of the art, it has been impossible to reclaim resources from such waste.

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Table 1

Composition of tires		
Component		Content (%)
Volatile	Raw rubber	40-50
	Oil	5-10
Fixed carbon		20-30
Steel & ash		10-15

With respect to the second aspect of the present invention, in conventional combustion systems for burning organic waste such as scrap tires and waste plastics, the organic waste is burned with a combustion-support gas comprising air or a mixture of air and combustion exhaust gas.

When scrap tires are taken as an example, they are composed of 50-60% of volatiles, 20-30% of fixed carbon, and 10-15% of inorganic matter such as steel and ash. Since scrap tires are elastic bodies including steel wires, it is difficult to crush them to small pieces. Accordingly, it has been conventional practice to burn whole scrap tires in a stoker or kiln or to cut scrap tires to a size of about 10 cm and burn them in a stoker or kiln. These combustion methods involve the following problems.

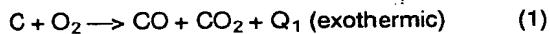
- (1) If scrap tires are burned with air, volatiles present therein are decomposed and burned rapidly. As a result, a high temperature of 1,500°C or above is attained locally, causing damage to the furnace. Moreover, large amounts of soot and tar are produced from the flame, requiring after-treatment.

(2) The fixed carbon remaining after the evaporation of volatiles has such a low burning rate that it may form a residue in admixture with inorganic matter. This residue is not easy to dispose of.

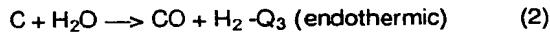
(3) On the other hand, if scrap tires are burned with a gaseous mixture of air and combustion exhaust gas, the problem described in the above paragraph (1) is alleviated. However, the problem described in the above paragraph (2) is aggravated owing to an increase in residual fixed carbon.

Thus, it is impossible to have an overall solution.

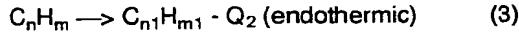
With respect to the third to sixth aspects of the present invention, an example of a conventional fixed-bed gasification furnace for gasifying organic waste such as scrap tires and waste plastics is illustrated in Fig. 24. In the fixed-bed gasification furnace 201 of Fig. 24, volatiles present in organic waste 206 fed from above are pyrolyzed and gasified by the heat evolved as a result of the partial combustion of fixed carbon present in the underlying residue, thus yielding a residue 207 consisting largely of fixed carbon. The fixed carbon present in residue 207 is partially burned and gasified with a gasifying agent 211 which is a mixture of an oxygen-containing gas and steam and which is supplied to a space below a perforated plate 204 through a valve 212, and the fixed carbon serves to supply the heat required to pyrolyze the volatiles. The gas produced by the pyrolysis and gasification of volatiles and the gas produced by the gasification of fixed carbon are mixed together and withdrawn as an organic waste-gasified gas 210. The reactions occurring during this process are represented by the following equations (1), (2) and (3).



(Supply of the heat of reaction by the partial combustion and gasification of fixed carbon)



(Gasification by the reaction of fixed carbon with steam)



($n > n1, m > m1$)

(Pyrolysis and gasification of volatiles)

If the pyrolysis temperature of volatiles is high (e.g., 700°C or above), C-C bonds are severed extensively, so that a low-molecular hydrocarbon gas consisting of low-molecular components such as methane (CH₄), ethane (C₂H₆) and ethylene (C₂H₄) are produced in high proportions. On the other hand, if the pyrolysis temperature is low (e.g., 500-700°C), a high-molecular hydrocarbon gas containing aromatic compounds such as benzene (C₆H₆), toluene (C₇H₈) and naphthalene (C₁₀H₈) is produced. This situation is schematically shown in Fig. 25.

When a gas obtained by the gasification of organic waste is used as the raw material for the formation of carbon black, the gas produced in the gasification furnace is introduced into a combustion furnace for the formation of carbon black, and burned in a low-oxygen environment to form carbon black. During this process, a gas consisting of low-molecular components is predominantly burned by reaction with oxygen, creating a high-temperature field. In this high-temperature field, a high-molecular hydrocarbon gas undergoes dehydrogenation and polycondensation repeatedly and thereby grows to form carbon black. That is, in order to enhance the yield of carbon black, it is preferable to increase the content of high-molecular components, such as naphthalene (C₁₀H₈) and anthracene (C₁₄H₁₀), in the gas obtained by the gasification of organic waste. To this end, it is preferable to carry out the pyrolysis of volatiles at a temperature of 500-700°C.

If the pyrolysis temperature is higher than 700°C, C-C bonds present in volatiles will be severed extensively to produce low-molecular hydrocarbons, such as methane (CH₄), ethane (C₂H₆) and ethylene (C₂H₄). If it is lower than 500°C, the pyrolysis will not proceed satisfactorily.

Usually, the quantity of heat required to pyrolyze and gasify volatiles at a temperature of 500-700°C will be only about 5-10% of the total quantity of heat possessed by organic waste. Where the content of fixed carbon in organic waste is high (e.g., 20%), the combustion of all fixed carbon will evolve an excessive quantity of heat.

Thus, where it is desired to produce a high-molecular hydrocarbon gas from volatiles in the gasification of organic waste, the following problems arise. They make it difficult to control the pyrolysis temperature of volatiles so as to remain in an appropriate range.

(1) If the feed rate of oxygen is reduced to decrease the amount of fixed carbon undergoing partial combustion (i.e., the heat of combustion, Q₁, of fixed carbon) and thereby lower the pyrolysis temperature, a residue containing fixed carbon is left. This residue is not easy to dispose of.

(2) Contrary, if fixed carbon is partially burned at a sufficiently high feed rate of oxygen so as not to leave any residual fixed carbon, the heat of combustion is increased to raise the pyrolysis temperature. As a result, a high-molecular hydrocarbon gas cannot be obtained.

(3) The reaction temperature can be lowered by adding steam to the gasifying agent. However, if the feed rate of steam is raised to increase the quantity of heat (Q_3) absorbed by the reaction of fixed carbon with steam, fixed carbon and unreacted steam react with the high-molecular hydrocarbon gas produced by the pyrolysis of volatiles, resulting in the formation of low-molecular hydrocarbons.



($n_1 > n_2, m_1 > m_2$)

Furthermore, as noted above, a proper temperature control is required to obtain a gas having a composition suitable for use as the raw material for the production of carbon black. In conventional fixed-bed gasification furnaces, the feed rate of the whole gasifying agent is usually controlled in response to the height of the organic waste layer within the furnace and this involves the following problems.

If the feed rate of organic waste varies, the resulting change in the feed rate of the gasifying agent is delayed because of the time lag of the change in the height of the organic waste layer. This causes the gasifying agent/organic waste ratio to become unbalanced. As a result, the supply of heat by the partial combustion and gasification of fixed carbon according to the above equations (1) and (2) also becomes unbalanced, so that the internal temperature of the gasification furnace may be fluctuated. Thus, the pyrolysis temperature of volatiles depending on equation (3) may be fluctuated to depart from its appropriate range. That is, if the feed rate of organic waste decreases, the gasifying agent/organic waste ratio temporarily becomes unduly high, resulting a rise in pyrolysis temperature. Contrarily, if the feed rate of organic waste increases, the gasifying agent/organic waste ratio temporarily becomes unduly low, resulting a reduction in pyrolysis temperature. Consequently, the properties of the resulting organic waste-gasified gas are fluctuated, bringing about unstable operation of the succeeding process (such as carbon black production process) using that gas.

Also, in order to hold down the pyrolysis temperature of volatiles, the partial combustion/gasification temperature of fixed carbon needs to be held down. Since the reaction rate of fixed carbon is reduced thereby, the organic waste layer becomes thick, requiring a large-sized fixed-bed gasification furnace.

SUMMARY OF THE INVENTION

An object of the first aspect of the present invention is to provide processes and systems for producing carbon black from waste which can dispose of organic waste such as scrap tires with easy operation and with high efficiency and, moreover, allow organic waste to be converted into a resource and reused as a raw material for the manufacture of valuable carbon black.

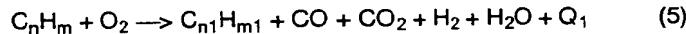
According to the first aspect of the present invention, there are provided:

- (1) a process for the production of carbon black which comprises the steps of partially burning and gasifying organic waste in a gaseous mixture of an oxygen-containing gas and steam with an equivalent ratio of oxygen to waste being 1 or less, partially burning the resulting combustible gas at a temperature of 1,000°C or above in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen, and quenching the resulting partial combustion gas having a temperature of 1,000°C or above to 700°C or below in an inert atmosphere;
- (2) a process for the production of carbon black which comprises the steps of pyrolyzing and gasifying organic waste at a temperature of 500°C or above in an oxygen-free environment, partially burning the resulting combustible gas at a temperature of 1,000°C or above in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen, and quenching the resulting partial combustion gas having a temperature of 1,000°C or above to 700°C or below in an inert atmosphere; and
- (3) a system for the production of carbon black from organic waste which comprises gasification means for partially burning and gasifying organic waste in a gaseous mixture of an oxygen-containing gas and steam with an equivalent ratio of oxygen to waste being 1 or less or for pyrolyzing and gasifying organic waste at a temperature of 500°C or above in an oxygen-free environment; a combustion furnace for partially burning the combustible gas obtained by said gasification means at a temperature of 1,000°C or above in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen; quenching means for quenching the partial combustion gas leaving said combustion furnace and having a temperature of 1,000°C or above to 700°C or below by means of water or nitrogen; collector means for separating and collecting the formed carbon black; and an exhaust gas treating apparatus for subjecting the exhaust gas obtained after the separation of carbon black to pollution control treatments.

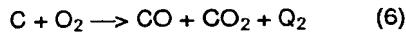
According to the first aspect of the invention, the gasification reactions occur in the partial combustion and gasification of organic waste in a gaseous mixture of an oxygen-containing gas and steam with an equivalent ratio of oxygen to be 1 or less, and they are represented by the following equations (5) to (9).

Namely, volatiles and fixed carbon are partially burned by reaction with oxygen, and the heat so evolved cause the pyrolysis of volatiles. In addition, volatiles are converted into low-molecular compounds by reaction with steam, and fixed carbon is gasified by reaction with steam. The temperature for these partial combustion and gasification is preferably in the range of 500 to 1,000°C. If the temperature is lower than 500°C, the pyrolysis reaction of volatiles according to equation (3) will not proceed satisfactorily. If it is higher than 1,000°C, the reactions (5) and (7) occur rapidly and a portion of the pyrolyzed volatiles (C_nH_m) undergo polycondensation in the oxygen-deficient environment to form tar and soot.

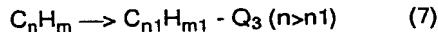
Also, if the combustion takes place in air the combustion temperature becomes high because of the lack of steam, and a part of decomposed volatiles (C_nH_m) undergo polycondensation to produce tar and soot.



(Exothermic reaction by the partial combustion of volatiles)



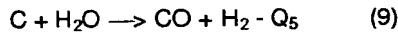
(Exothermic reaction by the partial combustion of fixed carbon)



(Pyrolysis of volatiles, endothermic reaction)



(Conversion of volatiles into low-molecular compounds by reaction with steam, endothermic reaction)



(Gasification of fixed carbon by reaction with steam, endothermic reaction)

In the above-described reactions, the gasification temperature and the composition of the resulting combustible gas can be controlled by varying the feed rates of oxygen and steam. Fig. 4 shows the relationship between the proportions of supplied oxygen and steam to carbon and the reaction characteristics in the gasification of scrap tires at 700°C.

In Fig. 4, the molar ratios of O_2 (oxygen) to C (carbon) and H_2O (steam) to C present in organic waste are plotted as ordinate and abscissa, respectively. As shown in Fig. 4, the gasification reactions are divided into five regions having different reaction patterns according to the proportions of O_2 and H_2O .

(1) Non-burning region: In this region, combustion cannot be sustained owing to a shortage of O_2 .

(2) Fixed carbon-remaining region: More O_2 than in region (1) is present and combustion is sustained. However, O_2 is still insufficient and H_2O is also scarce, so that some carbon remains unburned.

(3) Pyrolytic gas region: H_2O is increased as compared with region (2) and no carbon is left unburned. However, hydrocarbons are not yet converted into low-molecular compounds.

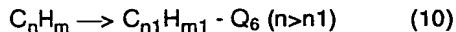
(4) Clean gas region: This is a region in which more H_2O than in region (3) is present. Hydrocarbons are converted into low-molecular compounds such as CO , H_2 and CH_4 .

(5) Coking region: This is a region in which O_2 is increased as compared with regions (3) and (4). The combustion temperature is elevated locally and rapidly pyrolyzed hydrocarbons undergo mutual polycondensation (coking) to form tar and soot.

In the first aspect of the present invention, it is necessary to produce large amounts of high-molecular hydrocarbons for the purpose of obtaining carbon black in high yield. The preferred conditions for this purpose (i.e., an equivalent ratio of oxygen of 0.3-0.5, and a steam equivalent ratio of about 2-3 in this example) are represented by the hatched area in Fig. 4.

The pyrolysis reaction occurring in the pyrolysis and gasification of organic waste at a temperature of 500°C or above in an oxygen-free environment is represented by the following equation (10).

The appropriate temperature for pyrolysis is 500°C or above and preferably in the range of 500 to 900°C. If the temperature is lower than 500°C, pyrolysis will not proceed satisfactorily, while if it is higher than 900°C, the resulting gas will consist of low-molecular components, resulting in a reduced yield of carbon black.



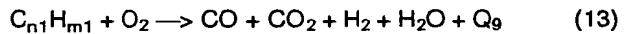
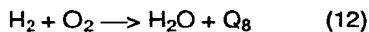
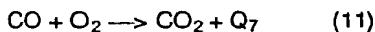
(Pyrolysis of volatiles, endothermic reaction)

In the processes of the present invention, the combustible gas obtained in the above-described manner (i.e., either by the partial combustion and gasification of organic waste in a gaseous mixture of an oxygen-containing gas and steam with an equivalent ratio of oxygen being 1 or less or by the pyrolysis and gasification of organic waste at a temperature of 500°C or above in an oxygen-free environment) is burned in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen required for combustion. Since any coarse particles present in this combustible gas may degrade the quality of carbon black, it is preferable to remove them by means of a cyclone or the like.

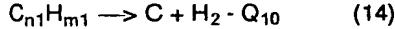
The reactions occurring in this step are represented by the following equations (11) to (14). The combustible gas is partially burned to create a high-temperature field at 1,000°C or above. In this high-temperature field, hydrocarbons are dehydrogenated and then mutually polycondensed owing to a shortage of oxygen. Thus, as shown in Fig. 5, hydrocarbons are converted into aromatics and then macromolecular aromatics, which condense into droplets and finally form carbon black particles.

During this process, the dehydrogenation reaction rate of hydrocarbons can be enhanced by attaining a temperature of 1,000°C or above, preferably 1,000 to 2,000°C. As a result, the diffusion of oxygen becomes insufficient and the proportion of mutually polycondensed hydrocarbons is increased, resulting in an enhanced yield of carbon black. The temperature seldom exceeds 2,000°C in the case of combustion in such low-oxygen conditions.

On the other hand, if the temperature is low, the proportion of hydrocarbons reacting with diffusing oxygen is increased, resulting in a reduced yield of carbon black. Moreover, the dehydrogenation reaction does not proceed satisfactorily, so that carbon black of high quality cannot be obtained.



(Exothermic reaction by the partial combustion of combustible gases)



(Formation of carbon black by the dehydrogenation and polycondensation of hydrocarbons)

Then, the reactions for the conversion of hydrocarbons into carbon black are stopped by instantaneously quenching the resulting partial combustion gas having a temperature of 1,000°C or above to a temperature of 700°C or below, preferably 200 to 700°C, in an inert atmosphere. If the partial combustion gas is cooled slowly, carbon black having different properties is formed at various temperatures in the course of the cooling, so that carbon black having uniform properties cannot be obtained. As the means of quenching, it is preferable to use water or an inert gas such as nitrogen which also may serve as a means for keeping the partial combustion gas in an inert atmosphere. The particle size, hydrogen content and other properties of carbon black can be controlled by regulating the timing of quenching. The preferred particle size range of carbon black is from 20 to 100 nm and the preferred hydrogen content range thereof is from about 0.3 to 0.5%. If the quenching temperature is less than 200°C, the dew point of any SO_x present in the partial combustion gas is reached, so that the recovery of carbon black becomes difficult.

Thereafter, carbon black can be obtained by separating and collecting it from the carbon black-containing reaction gas.

The carbon black produced in the above-described manner has a small particle size and a low bulk density (0.1 g/cm³ or less). If desired, its bulk density may be increased by granulating the carbon black with a wet granulator or the like and then drying it.

The first aspect of the present invention makes it possible to produce valuable carbon black from organic waste such as scrap tires which has conventionally been incinerated only for the purpose of utilizing the heat evolved by its combustion as a heat source. Moreover, although scrap tires and the like have had the disadvantage of requiring troublesome operations for their disposal, the processes of the present invention facilitate the disposal of such organic waste. The systems according to the first aspect enable the above-described processes to be carried out effectively.

An object of the second aspect of the present invention is to provide a method for the combustion of organic waste which can solve the problems of the conventional art.

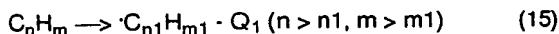
According to the second aspect of the present invention, there are provided:

(1) a method for the combustion of organic waste which comprises burning organic waste in a combustion furnace with a combustion-support gas prepared by mixing air and steam or mixing air, steam and combustion exhaust gas so as to have an oxygen concentration of 10 to 21%; and

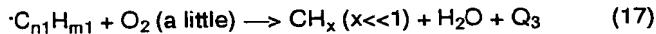
(2) a method for the combustion of organic waste which comprises passing the combustion exhaust gas produced by the method of (1) above through a heat exchanger to recover thermal energy therefrom in the form of steam, and using a portion of a resulting steam for the combustion-support gas to be fed to the combustion furnace.

The mechanism of the combustion of organic waste in air is as follows:

(1) The surfaces of organic waste are heated by heat radiation and heat transfer from a flame, so that the organic waste is pyrolyzed to form hydrocarbon radicals ($\cdot C_{n1}H_{m1}$) according to equation (15).



(2) Hydrocarbon radicals ($\cdot C_{n1}H_{m1}$) react with oxygen diffusing from the surroundings to form a flame [equation (16)]. During this process, if the rate of formation of hydrocarbon radicals is high, the diffusion of oxygen becomes insufficient. As a result, the polycondensation reaction of hydrocarbon radicals takes place, producing soot and tar [equation (17)].



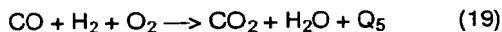
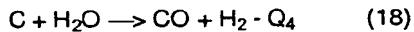
(3) On the other hand, fixed carbon present in organic waste has a low reaction rate and, moreover, hydrocarbon radicals take oxygen away. Consequently, it is quite likely that fixed carbon remains unreacted.

In contrast, the combustion method of the present invention uses, instead of air, a combustion-support gas prepared by mixing air and steam or mixing air, steam and combustion exhaust gas so as to give an oxygen concentration of 10 to 21%, and hence has the following effects.

(1) Since the heat of reaction of hydrocarbon radicals with oxygen is absorbed not only by nitrogen in air, but also by steam and carbon dioxide, the overall quantity of heat absorbed is increased to cause a reduction in flame temperature.

(2) Accordingly, the rate of formation of hydrocarbon radicals is reduced. This allows oxygen to diffuse sufficiently and thereby suppresses the production of soot and tar.

(3) Fixed carbon is also burned as a result of the sufficient diffusion of oxygen. Moreover, fixed carbon reacts with steam to produce carbon monoxide and hydrogen, which are then burned [equations (18) and (19)].



However, if the oxygen concentration is less than 10%, the hydrocarbon radicals formed by pyrolysis and the carbon monoxide and hydrogen produced by the reaction of fixed carbon with steam do not reach the explosion limit, so that they are not burned but discharged as an unburned gas. That is, the relationship between the oxygen concentration and the amount of soot and tar produced or the amount unburned gas produced is as shown in Fig. 12, which indicate that the appropriate range of the oxygen concentration is from 10 to 21%.

The method according to the second aspect of the present invention makes it possible to burn organic waste without producing soot or tar, without leaving any residual fixed carbon, and without causing damage to the furnace owing high temperatures.

It is an object of the third aspect of the present invention, in view of difficulties experienced in controlling the pyrolyzing temperature, to provide a fixed-bed gasification furnace which can pyrolyze volatiles present in organic waste in a temperature range suitable for the production of a high-molecular hydrocarbon gas without leaving any residual fixed carbon, as well as a method for gasifying organic waste by using such a furnace.

According to the third aspect of the present invention, there are provided:

(1) A fixed-bed gasification furnace wherein a gasifying agent comprising an oxygen-containing gas is supplied to said furnace charged with organic waste, volatiles present in the organic waste are pyrolyzed and gasified in the upper part of said furnace, and the residual fixed carbon is gasified by reaction with the gasifying agent in the lower

part of said furnace and also serves to supply the heat for pyrolysis of the volatiles, said furnace comprising two divided internal sections: a volatiles pyrolysis section for gasifying a portion of the residual fixed carbon by reaction with the gasifying agent and for pyrolyzing and gasifying the volatiles by the heat so evolved; and a fixed carbon partial combustion/gasification section for reacting surplus fixed carbon with the gasifying agent;

(2) A fixed-bed gasification furnace wherein a gasifying agent comprising an oxygen-containing gas is supplied to said furnace charged with organic waste, volatiles present in the organic waste are pyrolyzed and gasified in the upper part of said furnace, and the residual fixed carbon is gasified by reaction with the gasifying agent in the lower part of said furnace and also serves to supply the heat for pyrolysis of the volatiles, said furnace comprising: two divided internal sections: a volatiles pyrolysis section for gasifying a portion of the residual fixed carbon by reaction with the gasifying agent and for pyrolyzing and gasifying the volatiles by the heat so evolved, and a fixed carbon partial combustion/gasification section for reacting surplus fixed carbon with the gasifying agent; a first pipeline for supplying a first gasifying agent mainly to said volatiles pyrolysis section; and a second pipeline for supplying a second gasifying agent mainly to said fixed carbon partial combustion/gasification section, so as to allow the compositions and feed rates of the first and second gasifying agents to be controlled independently; and

(3) A method for the gasification of organic waste which comprises the steps of providing a fixed-bed gasification furnace which comprises two divided internal sections: a volatiles pyrolysis section for gasifying a portion of residual fixed carbon by reaction with a gasifying agent and for pyrolyzing and gasifying volatiles by the heat so evolved, and a fixed carbon partial combustion/gasification section for reacting only surplus fixed carbon with the gasifying agent; feeding organic waste to said furnace; and controlling the composition and feed rate of the gasifying agent for gasifying the organic waste, so that the temperature of said volatiles pyrolysis section is in the range of 500 to 700°C and the temperature of said fixed carbon partial combustion/gasification section is in the range of 700 to 1,500°C.

The fixed-bed gasification furnace of third aspect of the present invention and the gasification method using this furnace make it possible to produce a high-molecular hydrocarbon gas containing aromatic compounds from organic waste such as scrap tires and, moreover, to gasify such organic waste completely without leaving any residual fixed gas. The organic waste-gasified gas obtained according to the third aspect which contains a high-molecular hydrocarbon gas at a high concentration is especially suitable for use as a raw material for the manufacture of carbon black.

It is an object of the fourth aspect of the present invention, in view of problems associated with fluctuations in the feed rate of the organic waste, to provide a fixed-bed gasification furnace which can lessen fluctuations in the internal temperature of the furnace and thereby maintain a stable pyrolysis temperature, as well as a method for gasifying organic waste by using such a furnace.

According to the fourth aspect of the present invention, there are provided:

(1) a fixed-bed gasification furnace wherein organic waste charged thereto is gasified with supply of a gasifying agent comprising a mixture of an oxygen-containing gas and steam, said furnace comprises means for measuring the height of the layer of organic waste fed to said furnace, means for measuring the internal temperature of said furnace, a controller for controlling the feed rate of the oxygen-containing gas in response to a signal from said means for measuring the height of the organic waste layer, and a controller for controlling the feed rate of steam in response to a signal from said means for measuring the internal temperature of said furnace; and

(2) a method for gasifying organic waste by charging the organic waste into a fixed-bed gasification furnace and gasifying the organic waste with supply of a gasifying agent comprising a mixture of an oxygen-containing gas and steam, which method comprises: controlling the feed rate of the oxygen-containing gas in response to the height of the layer of organic waste fed to said furnace, and controlling the feed rate of steam in response to the internal temperature of said furnace, so as to carry out the gasification.

If the rate of feed of organic waste to the gasification furnace decreases, the height of the organic waste layer is reduced and the oxygen/organic waste ratio temporarily becomes unduly high, resulting in a rise in the internal temperature of the gasification furnace. Accordingly, the height of the organic waste layer within the furnace is measured continuously, and the feed rate of the oxygen-containing gas is decreased in response to a reduction in the height of the layer of organic waste (i.e., a decrease in the amount of organic waste within the furnace) so as to maintain an appropriate oxygen/organic waste ratio. Moreover, the internal temperature of the furnace (i.e., the temperature just above the organic waste layer) is also measured continuously, and the feed rate of steam is increased in response to a rise in temperature so as to suppress the temperature rise.

On the other hand, if the rate of feed of organic waste to the gasification furnace increases, the height of the organic waste layer is raised and the oxygen/organic waste ratio temporarily becomes unduly low, resulting in a drop in the internal temperature of the gasification furnace. Accordingly, the feed rate of the oxygen-containing gas is increased in response to a rise in the height of the organic waste layer (i.e., an increase in the amount of organic waste within the furnace) so as to maintain an appropriate oxygen/organic waste ratio. Moreover, the feed rate of steam is decreased in response to a drop in temperature so as to suppress the temperature drop.

Thus, by controlling the feed rates of the oxygen-containing gas and steam in the gasifying agent independently, the internal temperature of the gasification furnace can be controlled precisely so as to remain substantially constant in spite of variation in the feed rate of organic waste. Consequently, the pyrolysis temperature of volatiles is also kept substantially constant, so that an organic waste-gasified gas containing large amounts of high-molecular hydrocarbon components and having stabilized properties can be produced.

The gasification furnace of the present invention is suitable for use as a gasification furnace in a process for producing carbon black by using organic waste as raw material. However, it is also suitable for use as a fixed-bed gasification furnace for gasifying organic waste and coal to recover fuel oils and combustible gases.

It is also an object of the fifth aspect of the present invention to provide a fixed-bed gasification furnace which can lessen fluctuations in the internal temperature of the furnace and thereby maintain a stable pyrolysis temperature, as well as a method for gasifying organic waste by using such a furnace.

According to the fifth aspect of the present invention, there are provided:

- (1) a fixed-bed gasification furnace wherein organic waste charged thereto is gasified with supply of a gasifying agent comprising a mixture of an oxygen-containing gas and steam, said furnace comprising means for measuring the height of the layer of organic waste fed to said furnace, means for measuring the internal temperature of said furnace, a nozzle for supplying steam or nitrogen gas to a middle part of the organic waste layer, a controller for controlling the feed rate of the gasifying agent in response to a signal from said means for measuring the height of the organic waste layer, and a controller for controlling the feed rate of steam or nitrogen gas from said nozzle in response to a signal from said means for measuring the internal temperature of said furnace; and
- (2) a method for gasifying organic waste by charging the organic waste into a fixed-bed gasification furnace and gasifying the organic waste with supply of a gasifying agent comprising a mixture of an oxygen-containing gas and steam, said method comprising the steps of: supplying steam or nitrogen gas to a middle part of the layer of organic waste fed to said furnace; controlling the feed rate of the gasifying agent in response to the height of the organic waste layer; and controlling the feed rate of steam or nitrogen gas supplied to a middle part of the organic waste layer in response to the internal temperature of said furnace, so as to carry out the gasification of the organic waste.

In the fifth aspect of the present invention, the gasification temperature of volatiles in the volatiles pyrolysis region formed in the upper part of the organic waste layer within the furnace is controlled so as to be in the range of 500 to 700°C. If the temperature is lower than 500°C, the pyrolysis reaction will not proceed satisfactorily, while if it is higher than 700°C, the proportion of a high-molecular hydrocarbon gas will undesirably be reduced as stated before.

Moreover, the partial combustion/gasification temperature of fixed carbon in the fixed carbon partial combustion/gasification region formed in the lower part of the organic waste layer is preferably controlled so as to be in the range of 1,000 to 1,500°C. If the temperature is lower than 1,000°C, the reaction will be unduly slow, while if it is higher than 1,500°C, it will become difficult to control the gasification temperature of volatiles so as to be in the range of 500 to 700°C.

In order to control the gasification temperature of volatiles and the partial combustion/gasification temperature of fixed carbon so as to be in the above-described respective ranges, the present invention involves carrying out the gasification while controlling the feed rate of the gasifying agent in response to the height of the layer of organic waste fed to the furnace and supplying an appropriate amount of steam or nitrogen gas to a middle part of the organic waste layer in response to the internal temperature of the gasification furnace. As used herein, the term "middle part" means a part in the vicinity of the boundary between the volatiles pyrolysis region where the pyrolysis of volatiles occurs predominantly and the fixed carbon partial combustion/gasification region where the partial combustion and gasification of fixed carbon proceeds predominantly.

In the fifth aspect of the present invention, the feed rate of the gasifying agent is controlled in response to changes in the height of the organic waste layer so as to minimize fluctuations in the internal temperature of the gasification furnace. Moreover, if the internal temperature of the gasification furnace (i.e., the temperature in the vicinity of the surface of the organic waste layer) becomes high, the temperature of the gas obtained by the partial combustion and gasification of fixed carbon is reduced by supplying steam or nitrogen gas through a nozzle provided at a position corresponding to a middle part of the organic waste layer. Thus, the partial combustion and gasification of fixed carbon can be carried out at a high temperature of 1,000 to 1,500°C without affecting the appropriate pyrolysis temperature of volatiles which is in the range of 500 to 700°C. As a result, the reaction rate can be enhanced and the height of the organic waste layer can be reduced thereby. Furthermore, more CO than CO₂ is produced in the reaction of the above equation (1) and the equilibrium in equation (2) is shifted to the right side, resulting in the production of much CO and H₂ from fixed carbon. Thus, an organic waste-gasified gas containing large amounts of combustible components can be obtained.

That is, the internal temperature of the gasification furnace below the position of the nozzle can be kept substantially constant in spite of variation in the feed rate of organic waste. Consequently, the pyrolysis temperature of volatiles is also kept substantially constant, so that an organic waste-gasified gas containing large amounts of high-molecular hydrocarbon components and having stabilized properties can be produced.

The gasification furnace of the present invention is suitable for use as a gasification furnace in a process for producing carbon black by using organic waste as raw material. However, it is also suitable for use a fixed-bed gasification furnace for gasifying organic waste and coal to recover fuel oils and combustible gases.

It is also an object of the sixth aspect of the present invention to provide a fixed-bed gasification furnace which can lessen fluctuations in the internal temperature of the furnace and thereby maintain a stable pyrolysis temperature, as well as a method for gasifying organic waste by using such a furnace.

According to the sixth aspect of the present invention, there are provided:

(1) a fixed-bed gasification furnace wherein organic waste charged thereto is gasified with a gasifying agent supplied thereto, said furnace comprising:

two divided internal sections: an A-compartment where a raw material is fed and volatiles present therein are predominantly pyrolyzed and gasified, and a B-compartment where the residue consisting largely of fixed carbon which remains after most of the volatiles have been pyrolyzed and gasified is introduced and burned or gasified;

means for detecting the internal temperature of the A-compartment and controlling the feed rate of the gasifying agent supplied to the A-compartment in response to the measured value thereof;

means for detecting the height of the organic waste layer in the A-compartment and controlling the feed rate of the gasifying agent supplied to the B-compartment in response to the measured value thereof; and

means for detecting the height of the residue layer in the B-compartment and controlling the amount of residue introduced from the A-compartment into the B-compartment in response to the measured value thereof; and

(2) a method for gasifying organic waste by charging the organic waste into a fixed-bed gasification furnace and gasifying the organic waste with a gasifying agent supplied to said furnace, said method comprising the steps of: using a fixed-bed gasification furnace comprising two divided internal sections: an A-compartment where a raw material is fed and volatiles present therein are predominantly pyrolyzed and gasified, and a B-compartment where the residue consisting largely of fixed carbon which remains after most of the volatiles have been pyrolyzed and gasified is introduced and burned or gasified; detecting the internal temperature of the A-compartment; controlling the feed rate of the gasifying agent supplied to the A-compartment in response to the measured value thereof; detecting the height of the organic waste layer in the A-compartment; controlling the feed rate of the gasifying agent supplied to the B-compartment in response to the measured value thereof; detecting the height of the residue layer in the B-compartment; and controlling the amount of residue introduced from the A-compartment into the B-compartment in response to the measured value thereof, so as to carry out the gasification of organic waste.

The internal space of the fixed-bed gasification furnace of the present invention is divided into an A-compartment where a raw material is fed and volatiles present therein are predominantly pyrolyzed and gasified, and a B-compartment where the residue consisting largely of fixed carbon which remains after most of the volatiles have been pyrolyzed and gasified is introduced and burned or gasified. Organic waste used as the raw material is charged into the A-compartment and heated to 500-700°C by a gas produced in the lower part thereof as a result of the combustion or gasification of the residue consisting largely of fixed carbon by reaction with a gasifying agent supplied, so that most of the volatiles present in the organic waste are pyrolyzed and gasified. After most of the volatiles have been removed by pyrolysis and gasification, the resulting residue consisting largely of fixed carbon moves to the B-compartment which communicates with the A-compartment in the lower part of the gasification furnace, and is burned or gasified at 1,000-1,500°C with a gasifying agent supplied. The gas emerging from the A-compartment, which consists largely of a gas produced by the pyrolysis and gasification of volatiles, and the gas emerging from the B-compartment, which consists largely of a gas produced by the combustion or gasification of residue, were mixed together in the upper part of the gasification furnace and withdrawn as an organic waste-gasified gas.

As the gasifying agents supplied to the A- and B-compartments, there may be used an oxygen-containing gas, such as air, oxygen or oxygen-enriched air, and/or steam. Usually, it is preferable to supply an oxygen-containing gas to the A-compartment and a gaseous mixture of an oxygen-containing gas and steam to the B-compartment.

In the gasification furnace of the present invention, gasification can be carried out in an appropriate temperature range by controlling the feed rates of the gasifying agents supplied to the A- and B-compartments and the amount of residue introduced from the A-compartment into the B-compartment. Specifically, during the operation of the gasification furnace, the internal temperature of the A-compartment is detected and used to control the feed rate of the gasifying agent supplied to the A-compartment in response to the measured value thereof, the height of the organic waste layer in the A-compartment is detected and used to control the feed rate of the gasifying agent supplied to the B-compartment in response to the measured value thereof, and the height of the residue layer in the B-compartment is detected and used to control the amount of residue introduced from the A-compartment into the B-compartment in response to the measured value thereof.

If the rate of feed of organic waste to the gasification furnace decreases, the height of the organic waste layer in the A-compartment is reduced and the oxygen/organic waste ratio temporarily becomes unduly high, resulting in a rise in the pyrolysis/gasification temperature. Accordingly, the internal temperature of the A-compartment is measured con-

tinuously, and the feed rate of the gasifying agent supplied to the A-compartment is decreased in response to a rise in the internal temperature thereof so as to suppress the temperature rise.

If the feed rate of the gasifying agent supplied to the A-compartment decreases, the organic waste layer is elevated. Then, the rate of gasification of the residue consisting largely of fixed carbon is enhanced by increasing the feed rate of the gasifying agent supplied to the B-compartment, so that the height of residue in the B-compartment is reduced. Consequently, the height of the organic waste layer in the A-compartment can be reduced by raising the rate of movement of the residue from the A-compartment to the B-compartment. As soon as the organic waste layer in the A-compartment has become sufficiently low, the feed rate of the gasifying agent supplied to the B-compartment is decreased. In this manner, stable operation can eventually be achieved.

On the other hand, if the rate of feed of organic waste to the gasification furnace increases, the height of the organic waste layer in the A-compartment is raised and the oxygen/organic waste ratio temporarily becomes unduly low, resulting in a drop in pyrolysis/gasification temperature. Accordingly, the feed rate of the gasifying agent supplied to the A-compartment is increased in response to a drop in the internal temperature thereof so as to suppress the temperature drop.

If the feed rate of the gasifying agent supplied to the A-compartment increases, the organic waste layer is lowered. Then, the rate of gasification of the residue consisting largely of fixed carbon is reduced by decreasing the feed rate of the gasifying agent supplied to the B-compartment, so that the height of residue in the B-compartment is raised. Consequently, the height of the organic waste layer in the A-compartment can be raised by reducing the rate of movement of the residue from the A-compartment to the B-compartment. As soon as the organic waste layer in the A-compartment has become sufficiently high, the feed rate of the gasifying agent supplied to the B-compartment is decreased. In this manner, stable operation can eventually be achieved.

Thus, the gasification furnace of the sixth aspect of present invention makes it possible to maintain the internal temperature of the gasification furnace at a substantially constant level in spite of variation in the feed rate of organic waste. Consequently, the pyrolysis temperature of volatiles is also kept substantially constant, so that an organic waste-gasified gas containing large amounts of high-molecular hydrocarbon components and having stabilized properties can be produced.

The gasification furnace of the sixth aspect of the present invention is suitable for use as a gasification furnace in a process for producing carbon black by using organic waste as raw material. However, it is also suitable for use a fixed-bed gasification furnace for gasifying organic waste and coal to recover fuel oils and combustible gases.

30 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating a first preferred embodiment of the system of the first aspect of the present invention;

Fig. 2 is a block diagram illustrating a second preferred embodiment of the system of the first aspect;

Fig. 3 is a block diagram illustrating a third preferred embodiment of the system of the first aspect;

Fig. 4 is a graph showing the relationship between the proportions of supplied oxygen and steam to carbon and the reaction characteristics in the gasification of scrap tires at 700°C;

Fig. 5 is a schematic diagram illustrating the mechanism of formation of carbon black;

Fig. 6 is a schematic view illustrating a basic testing system for carrying out the processes of the first aspect of the present invention;

Fig. 7 is a schematic diagram illustrating a first exemplary carbon black production process in accordance with the first aspect;

Fig. 8 is a schematic diagram illustrating a second exemplary carbon black production process in accordance with the first aspect;

Fig. 9 is a schematic diagram illustrating a third exemplary carbon black production process in accordance with the first aspect;

Fig. 10 is a block diagram illustrating one embodiment of the method for the combustion of organic waste in accordance with the second aspect of the present invention;

Fig. 11 is a schematic diagram illustrating an exemplary combustion furnace for carrying out the combustion method of the second aspect of the present invention;

Fig. 12 is a graph schematically showing the relationship between the concentration of oxygen during combustion of organic waste and the amount of soot and tar produced or the amount of unburned gas components produced;

Fig. 13 is a schematic representation of a first embodiment of the fixed-bed gasification furnace of the third aspect of the present invention;

Fig. 14 is a schematic representation of a second embodiment of the fixed-bed gasification furnace of third aspect;

Fig. 15 is a graph showing the relationships between the air/fixed carbon ratio λ_c and the fixed carbon gasification temperature T_c and between the air/fixed carbon ratio λ_c and the temperature $T_g 1$ after the pyrolysis and gasification of volatiles by using all of the resulting fixed carbon-gasified gas, as determined in a case where scrap tires are gasified with the aid of air;

Fig. 16 is a graph showing the relationship between the distribution ratio a of the fixed carbon-gasified gas distributed between two divisions of the gasification furnace and the temperature T_g2 after the pyrolysis and gasification of volatiles;

5 Fig. 17 is a schematic view illustrating an example of the fixed-bed gasification furnace of the third aspect;

Fig. 18 is a schematic view illustrating another example of the fixed-bed gasification furnace of the third aspect;

Fig. 19 is a schematic view illustrating an example of the fixed-bed gasification furnace of the fourth aspect of the present invention;

Figs. 20(a) and 20(b) are graphs showing the state of control of the oxygen and steam feed rates in the example of the fourth aspect of the present invention (example 9);

10 Fig. 21 is a schematic view illustrating an example of the fixed-bed gasification furnace of the fifth aspect of the present invention;

Fig. 22(a) and 22(b) are graphs showing the state of control of the gasifying agent and nitrogen feed rates in the example of the fifth aspect of the present invention (example 10);

15 Fig. 23 is a schematic view illustrating an example of the fixed-bed gasification furnace of the sixth aspect of the present invention;

Fig. 24 is a schematic representation of an example of a conventional furnace for the gasification of organic waste; and

Fig. 25 is a graph schematically showing the relationship between the pyrolysis temperature of organic waste and the composition of the gas so produced.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of systems according to the first aspect of the present invention are illustrated in Figs. 1-3.

In the embodiment of Fig. 1, a gasification/combustion furnace 4 is formed by uniting a gasification section 6 constituting a means of gasification, a combustion section 7 functioning as a combustion furnace, and a quenching section 9 constituting a means of quenching. When organic waste such as scrap tires is fed to this gasification and combustion furnace 4, it is partially burned and gasified under the condition that the equivalent ratio of oxygen is 1 or less in gasification section 6 to which an oxygen-containing gas 16, such as air, oxygen-enriched air or oxygen, and steam 17 are supplied.

30 In the succeeding combustion section 7 to which an oxygen-containing gas 18, such as air, oxygen-enriched air or oxygen, is supplied, the combustible gas produced in gasification section 6 is partially burned at a temperature of 1,000°C or above in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen. The resulting partial combustion gas having a temperature of 1,000°C or above is quenched in quenching section 9 by the addition of water or nitrogen 19 so as to stop the reactions.

35 The carbon black-containing combustion gas 10 thus obtained is introduced into a collector, such as bag filter 11, where carbon black 12 is collected. The collected carbon black 12 is suitably granulated and dried to yield a product.

On the other hand, combustion exhaust gas 13 from which carbon black 13 has been separated is subjected to pollution control treatments, such as desulfurization, denitration and dust removal, in an exhaust gas treating apparatus 14 and discharged into the atmosphere as a treated exhaust gas 15.

40 In the embodiment of Fig. 2, a gasification furnace 2 serving as a means of gasification is installed independently. The combustible gas 5 obtained by effecting therein the same reaction as in the gasification section 6 of Fig. 1 is introduced into a combustion furnace 8 coupled with a quenching section 9, where it is partially burned and then quenched. The flow after quenching section 9 is the same as in the embodiment of Fig. 1.

45 In the embodiment of Fig. 3, a pyrolysis furnace 3 is installed in place of the gasification furnace 2 employed in the embodiment of Fig. 2. Thus, organic waste 1 is pyrolyzed and gasified at a temperature of 500°C or above in an oxygen-free environment to obtain a combustible gas (or pyrolytic gas) 5. The flow after combustion furnace 8 is the same as in the embodiment of Fig. 2.

50 In the embodiments of Figs. 1-3, gasification furnace 2, pyrolysis furnace 3 and gasification/combustion furnace 4 are equipped with a means for the separation of ash (or pyrolytic residue). If necessary, a dust removal device may be installed prior to the introduction of the combustible gas produced by gasification or pyrolysis into the combustion furnace.

Furthermore, combustible components are still contained in the combustion exhaust gas 13 from which carbon black 12 has been separated. If desired, therefore, combustion exhaust gas 13 may be introduced into a boiler where it is burned to generate steam for purposes of heat recovery. This steam can also be utilized in the gasification of organic waste.

55 The first aspect of the present invention will now be explained in more details with reference to the following examples.

(Example 1)

Fig. 6 is a schematic view illustrating a basic testing system for the production of carbon black from organic waste. This system consists of a main test apparatus 20 having a gasification section 6, a combustion section 7 and a quenching section 9, and a collector 11. In the operation of this system, organic waste 1 is first placed on a fire grate 21 in gasification section 6 and gasified (1) by supplying, from the underside of fire grate 21, a gasifying agent 22 comprising a mixture of air, oxygen and steam in any desired proportions and preheated to any desired temperature up to 700°C or (2) by supplying, from the underside of fire grate 21, a gasifying agent 22 comprising nitrogen gas or the like and preheated to a temperature of 500°C or above.

In combustion section 7, the combustible gas 5 so produced is burned in an oxygen-deficient environment by supplying a burning gas 24 comprising a mixture of air and oxygen in any desired proportions through a nozzle 23. Then, the resulting combustion gas is quenched in quenching section 9 by introducing nitrogen gas 26 through a nozzle 25. The carbon black-containing combustion gas thus obtained is introduced into a collector 11, such as bag filter, where carbon black is separated and collected. The compositions and temperatures of gasifying agent 22 and burning gas 24 may be suitably controlled according to the properties of organic waste 1.

The processes for producing carbon black in the above-described system by using scrap tires as the organic waste are more specifically described below.

(Gasification section)

(1) Scrap tires, which have been crushed to about 1 cm cubic chips, are charged onto fire grate 21 at a feed rate of 5 kg per hour. On the other hand, a gasifying agent 22 comprising a 1:1 mixture of air and steam and preheated to 700°C is supplied at a feed rate of 50 N liters per minute. Thus, all of the scrap tires are gasified except for steel and ash.

(2) Scrap tires, which have been crushed to about 1 cm cubic chips, are charged onto fire grate 21 at a feed rate of 5 kg per hour. On the other hand, nitrogen gas preheated to 700°C is supplied at a feed rate of 50 N liters per minute. Thus, volatiles such as raw rubber and oil are pyrolyzed and gasified.

(Combustion section)

The combustible gas 5 obtained in the above step (1) or (2) is partially burned at a temperature of 1,000°C or above with the aid of a burning gas 24 comprising a 1:1 mixture of air and oxygen which is supplied through nozzles 23 above the fire grate at a feed rate of 10 N liters per minute.

(Quenching section)

The combustion gas from the combustion section is quenched to 700°C or below by supplying nitrogen gas thereto through nozzle 25 at a flow rate of 50 N liters per minute. Thus, there is obtained a combustion gas containing carbon black.

(Collector)

The above combustion gas containing carbon black is introduced into the collector (or bag filter) where carbon black is separated and collected. The yield of carbon black is about 1 kg per hour.

(Example 2)

Fig. 7 is a schematic diagram illustrating an exemplary industrial-scale process using the system of Fig. 1. This process is operated as follows.

1. Scrap tires used as organic waste 1 are cut into about 10 cm cubes and fed to a gasification/combustion furnace 4.
2. In the gasification section 6 of gasification/combustion furnace 4 to which air or oxygen-enriched air 16' and steam 17 are supplied, a portion of organic waste (scrap tires) 1 is burned to evolve heat and thereby raise the internal temperature to 700°C or above.
3. A combustible gas 5 containing CO, H₂, CH₄ and high-molecular hydrocarbon compounds such as tar is produced from organic waste (scrap tires) 1. The remainder is withdrawn as inorganic ash 27.
4. In its combustion section 7 to which air or oxygen-enriched air 18' is supplied, the combustible gas 5 produced in gasification section 6 is partially burned at 1,500°C in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen to form carbon black 12.

5. In its quenching section 9, the combustion gas containing carbon black 12 is quenched to 500°C by the addition of water 19' to stop the reactions.
6. The carbon black-containing combustion gas 10 so produced is conveyed to a bag filter 28 where carbon black 12 is collected. This carbon black 12 is suitably granulated and dried to yield a product.
7. Since combustible components remain in the combustion exhaust gas 13 from which carbon black 12 has been separated, this combustion exhaust gas 13 is burned in a boiler 29 to generate steam 30.
8. A portion of steam 30 is used as a part of steam 17 supplied to gasification section 6 and the remainder is utilized as a heat source.
9. The combustion exhaust gas 13 whose combustible components have been burned in boiler 29 is treated in an exhaust gas treating apparatus 14 as required. The resulting pollution-free exhaust gas is discharged into the atmosphere.

(Example 3)

Fig. 8 is a schematic diagram illustrating an exemplary industrial-scale process using the system of Fig. 2. In this process, a cyclone 31 is installed between a gasification furnace 2 and a combustion furnace 8 provided with a quenching section 9 in order to remove coarse particles from the combustible gas. This process is operated as follows.

1. Scrap tires used as organic waste 1 are cut into about 10 cm cubes and fed to gasification furnace 2.
2. In gasification furnace 2 to which air or oxygen-enriched air 16' and steam 17 are supplied, a portion of organic waste (scrap tires) 1 is burned to evolve heat and thereby raise the internal temperature to 700°C or above.
3. A combustible gas 5 containing CO, H₂, CH₄, aromatic compounds, such as benzene and toluene, and high-molecular hydrocarbon compounds such as tar is produced from organic waste (scrap tires) 1. The remainder is withdrawn as inorganic ash 27.
4. Dust is removed from combustible gas 5 by means of cyclone 31. Then, in combustion furnace 8 to which air or oxygen-enriched air 18' is supplied, combustible gas 5 is partially burned at 1,500°C in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen, preferably at an oxygen/carbon ratio of 0.1-0.5, to form carbon black 12. If the oxygen-carbon ratio is less than 0.1, combustible gas 5 cannot be burned, while if it is greater than 0.5, the yield of carbon black is reduced.
5. In its quenching section 9, the combustion gas containing carbon black 12 is quenched to 500°C by the addition of water 19' to stop the reactions.
6. The carbon black-containing combustion gas 10 so produced is conveyed to a bag filter 28 where carbon black 12 is collected. This carbon black 12 is suitably granulated and dried to yield a product.
7. Since combustible components remain in the combustion exhaust gas 13 from which carbon black 12 has been separated, this combustion exhaust gas 13 is burned in a boiler 29 to generate steam 30.
8. A portion of steam 30 is used as a part of steam 17 supplied to gasification section 6 and the remainder is utilized as a heat source.
9. The combustion exhaust gas 13 whose combustible components have been burned in boiler 29 is treated in an exhaust gas treating apparatus 14 as required. The resulting pollution-free exhaust gas is discharged into the atmosphere.

(Example 4)

Fig. 9 is a schematic diagram illustrating an exemplary industrial-scale process using the system of Fig. 3. In this process, a pyrolysis furnace 3 is used as the means of gasification. This process is operated as follows.

1. Scrap tires used as organic waste 1 are cut into about 10 cm cubes and fed to pyrolysis furnace 3 by way of double dampers 32.
2. Within pyrolysis furnace 3 having a temperature of 600°C, scrap tires are pyrolyzed while traveling on a stoker 33. The residue is withdrawn by way of double dampers 34.
3. A portion of the resulting combustible gas (pyrolytic gas) 5 consisting largely of light oils such as benzene, toluene, xylene and styrene is mixed with air 36 and burned with burners for the purpose of heating pyrolysis furnace 3.
4. The remainder of combustible gas (pyrolytic gas) 5 is introduced into a combustion furnace 8 to which air 18" is supplied, and partially burned at 1,000-1,500°C in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen, preferably at an oxygen/carbon ratio of 0.1-0.5, to form carbon black 12. If the oxygen-carbon ratio is less than 0.1, combustible gas 5 cannot be burned, while if it is greater than 0.5, most of combustible gas 5 is burned, resulting in a reduced yield of carbon black.
5. In its quenching section 9, the combustion gas containing carbon black 12 is quenched to 500°C by the addition of water to stop the reactions.

6. The carbon black-containing combustion gas 10 so produced is conveyed to a bag filter 28 where carbon black 12 is collected. This carbon black 12 is suitably granulated and dried to yield a product.

7. The combustion exhaust gas 13 from which carbon black 12 has been separated is treated in an exhaust gas treating apparatus 14 as required. The resulting pollution-free exhaust gas is discharged into the atmosphere.

In the following, one embodiment of the method for the combustion of organic waste in accordance with the second aspect of the present invention is described hereinbelow with reference to Fig. 10. According to the combustion method of the second aspect, organic waste 101 is burned in a combustion furnace 2 which is supplied with a combustion-support gas prepared by mixing air 103, steam 105 and, if necessary, combustion exhaust gas 104, so as to give a predetermined oxygen concentration, as shown in Fig. 10. The combustion gas 108 so produced is passed through a heat exchanger 109 where thermal energy is recovered in the form of steam 110, and a portion of steam 110 is supplied to combustion furnace 102. Moreover, a portion of the resulting combustion exhaust gas 111 is supplied to combustion furnace 102 as required, and the remainder is subjected to pollution control treatments (such as dust removal and desulfurization) by means of a pollution control apparatus 112 and then discharged into the atmosphere as a treated exhaust gas 113.

Fig. 11 is a schematic diagram illustrating an exemplary combustion furnace for carrying out the method for the combustion of organic waste in accordance with the present invention.

In Fig. 11, organic waste 101, such as scrap tires and waste plastics, is fed to a combustion furnace 102. On the other hand, air 103 and steam 105 are supplied to combustion furnace 102 from the underside of a stoker 106. The oxygen concentration should be adjusted to 10-21%. For example, an oxygen concentration of 15% is obtained by supplying air and steam at a ratio of 1:0.5. If necessary, combustion exhaust gas 104 may be added for the purpose of adjusting the oxygen concentration.

The preferred gas for use in the adjustment of the oxygen concentration is steam. The reason for this is that steam reacts with and gasifies fixed carbon according to the above equation (18), the resulting high endotherm is highly effective in reducing the temperature of the combustion field, and the CO and H₂ so produced can be easily subjected to complete combustion in the presence of oxygen. However, steam is usually supplied from a boiler installed behind. If the amount of steam used is too large, the amount of steam which can be utilized effectively is decreased. In such a case, a part of the steam may be replaced by combustion exhaust gas.

Under these conditions, organic waste 101 is completely burned without producing soot or tar and without leaving any residual fixed carbon. The only residue on stoker 106 is inorganic matter 107, which is withdrawn later. The combustion temperature is in the range of 1,000 to 1,500°C.

Energy is recovered from combustion gas 108 by generating steam 110 by means of a heat exchanger 109. A part of the steam so generated can be used as steam 105 to be supplied to combustion furnace 102.

The resulting combustion exhaust gas 111 is further treated in a pollution control apparatus and discharged into the atmosphere as a treated exhaust gas 113. If necessary, a part of this combustion exhaust gas 111 is used as combustion exhaust gas 104 to be supplied to combustion furnace 102.

The method of the second aspect of the present invention is more specifically explained with reference to the following examples.

40 (Example 5)

Using the combustion furnace (3 m in diameter and 7 m in height) illustrated in Fig. 11, scrap tires (composed of 50-60% of volatiles, 20-30% of fixed carbon, and 10-15% of inorganic matter) were subjected to a combustion test.

Scrap tires were burned with a combustion-support gas prepared by mixing air and steam at a ratio of 1:0.5 so as 45 to give an oxygen concentration of 15% or by mixing air, steam and combustion exhaust gas at a ratio of 1:0.25:0.25 so as to give an oxygen concentration of 15%. The feed rates of scrap tires and air were 1 t/h and 12 t/h, respectively.

In either case, the combustion temperature was in the range of 1,000-1,500°C. The combustion exhaust gas consisted largely of CO₂, H₂O and N₂, showing no production of soot or tar. The combustion residue consisted entirely of steel and inorganic components present in tires, showing no residual fixed carbon. Thus, there were obtained good 50 combustion results. In the case where air, steam and combustion exhaust gas were used as described above, about 7 t/h (7 kgf/cm², 180°C) of steam was recovered.

(Example 6)

55 In the combustion test of Example 5, steam (at 500°C) generated by heat exchange with the combustion exhaust gas used as the steam to be added to the combustion-support gas. As a result, similarly good combustion results were obtained.

The third aspect of the present invention will now be explained with reference to Figs. 13-18.

Fig. 13 is a schematic representation of a first embodiment of the fixed-bed gasification furnace of the third aspect of the present invention. The internal space of this fixed-bed gasification furnace 201 is vertically divided by a partition (such as dividing plate) 214 into two sections, i.e., a volatiles pyrolysis section 202 and a fixed carbon partial combustion/pyrolysis section 203. Under partition 214, a space is formed so as to allow the residue consisting largely of fixed carbon 207 to move from volatiles pyrolysis section 202 to fixed carbon partial combustion/pyrolysis section 203. Organic waste (such as scrap tires and waste plastics) 206 is fed to volatiles pyrolysis section 202, where volatiles present in organic waste 206 are heated by the fixed carbon combustion gas 213 resulting from the partial combustion of a portion of fixed carbon 207, and thereby pyrolyzed and gasified to produce a volatiles-gasified gas 208. The remainder of fixed carbon 207 moves to fixed carbon partial combustion/pyrolysis section 203, where it is partially burned to produce a fixed carbon-gasified gas 209. In the upper part of fixed-bed gasification furnace 201, volatiles-gasified gas 208 and fixed carbon-gasified gas 209 are mixed together to produce an organic waste-gasified gas 210. Reference numeral 211 designates a gasifying agent supplied to a space below a perforated plate 204 through a gasifying agent supply pipeline 205 equipped with a valve 212.

In this gasification furnace, the temperature of volatiles pyrolysis section 202 is controlled so as to be in the range of 500 to 700°C. If the temperature is lower than 500°C, the pyrolysis reaction will not proceed satisfactorily, while if it is higher than 700°C, the proportion of a high-molecular hydrocarbon gas will undesirably be reduced as stated before.

The temperature of fixed carbon partial combustion/pyrolysis section 203 should be in the range of about 700 to 1,500°C, though it may vary according to the air ratio and other factors. If the temperature is lower than 700°C, partial combustion will not be sustained, while if the temperature is higher than 1,500°C, problems such as furnace damage may arise.

The temperatures of volatiles pyrolysis section 202 and fixed carbon partial combustion/pyrolysis section 203 can be controlled by regulating the feed rate of gasifying agent 211 (i.e., the air ratio) and the distribution ratio.

For example, when the air ratio with respect to fixed carbon (i.e., the proportion of air to its stoichiometric amount for a given amount of combustibles) λ_c , is varied in a case where scrap tires are gasified with the aid of air, the fixed carbon gasification temperature T_c and the temperature T_g1 after the pyrolysis and gasification of volatiles by using all of the resulting fixed carbon-gasified gas change as shown in Fig. 15. As is obvious from Fig. 15, fixed carbon remains when $\lambda_c \leq 0.5$. On the other hand, T_g1 exceeds 750°C when $\lambda_c \geq 0.6$, so that a volatiles-gasified gas having a high content of high-molecular components cannot be produced. That is, the appropriate range of the air/fixed carbon ratio is so narrow that the temperature control is difficult.

However, when the internal space of the gasification furnace is divided into a volatiles pyrolysis section and a fixed carbon partial combustion/pyrolysis section and the fixed carbon-gasified gas is distributed between these sections, the relationship between the temperature T_g2 after the pyrolysis and gasification of volatiles and the distribution ratio a is as shown in Fig. 16, even at a λ_c of 0.6. Thus, T_g2 can be kept within the range of 500 to 700°C.

The high-molecular components such as aromatic hydrocarbons present in the volatiles-gasified gas once produced are stable at temperatures up to about 850°C. Even if the volatiles-gasified gas is mixed with the bypassed fixed carbon-gasified gas, the former is heated only to about 750°C and hence undergoes no compositional change.

Fig. 14 is a schematic representation of a second embodiment of the fixed-bed gasification furnace of the present invention. This gasification furnace is substantially the same as that of Fig. 13, except that the former has two gasifying agent supply pipelines 205' and 205" which make it possible to supply two gasifying agents 211' and 211" having different compositions and feed rates through valves 212' and 212", respectively. In this manner, gasifying agents having different compositions and feed rates can be separately supplied to the volatiles pyrolysis section and the fixed carbon partial combustion/pyrolysis section, so that the temperature control becomes easier.

As the gasifying agent, there may be used an oxygen-containing gas such as air or a gas having steam added thereto. When the gasifying agent contains steam, it has the effect of reducing the partial combustion/gasification temperature according to the above-described equation (3). However, if unreacted steam comes into contact with the volatiles-gasified gas in the upper part of the gasification furnace, the high-molecular hydrocarbon gas is converted into a low-molecular one according to the above-described equation (4). Accordingly, steam should be added in such an amount that the molar equivalent ratio of steam to fixed carbon (H_2O/C) is not greater than 1.

Where two gasifying agent supply pipelines for supplying gasifying agents having different compositions to the volatiles pyrolysis section and the fixed carbon partial combustion/pyrolysis section are provided as seen in the gasification furnace of Fig. 14, it is preferable to omit the supply of steam to the volatiles pyrolysis section or supply steam to the volatiles pyrolysis section at a lower feed rate than to the fixed carbon partial combustion/pyrolysis section.

The third aspect of the present invention is more specifically explained with reference to the following examples.

55 (Example 7)

Fig. 17 is a schematic view illustrating an example of the fixed-bed gasification furnace of the present invention. This fixed-bed gasification furnace 201 has a gently sloping rotatable conical perforated plate 204 and an inner casing 216 defining an A-compartment 215 (i.e., a volatiles pyrolysis section) above it, within an outer casing 216 constituting

the outer wall of fixed-bed gasification furnace 201. Inner casing 215 and outer casing 216 are dimensioned so that the ratio of the cross-sectional area of inner casing 215 to the cross-sectional area of the space between inner casing 215 and outer casing 216 (i.e., a B-compartment 218 constituting a fixed carbon partial combustion/gasification section) is equal to about 1:1. To a space below perforated plate 204, air 223 is supplied as a gasifying agent through a gasifying agent supply pipeline 205 and valves 212.

Using this fixed-bed gasification furnace 201, scrap tires providing a typical example of organic waste were subjected to a gasification test. Excepting steel and ash, scrap tires contain about 70% by weight of volatiles (such as raw rubber and oil) and about 30% by weight of carbon black (fixed carbon).

Scrap tires 220, which had been cut into pieces, were fed to the upper part of A-compartment 217 within inner casing 215 through a charging chute 219. These scrap tires 220 were heated by a gas produced in the lower part of A-compartment 217 as a result of the partial combustion of a portion of the fixed carbon present in residue 221 with the aid of air 223 supplied as a gasifying agent through one valve 212, so that volatiles present therein were pyrolyzed and gasified to produce a volatiles-gasified gas 208. After removal of the volatiles, the resulting residue (consisting largely of fixed carbon) 221 moved to B-compartment 218 with the rotation of perforated plate 204, and was partially burned and gasified with the aid of air 223 supplied as a gasifying agent through the other valve 212. The fixed carbon-gasified gas 209 so produced was mixed with volatiles-gasified gas 208 in the upper part of the gasification furnace to produce a scrap tire-gasified gas 222.

The proportions of the gasifying agents supplied to A-compartment 217 and B-compartment 218 may be arbitrarily regulated according to the composition of organic waste used and other factors. Besides an oxygen-containing gas such as air, such a gas having an appropriate amount of steam added thereto can also be used as the gasifying agent.

(Example 8)

Fig. 18 is a schematic view illustrating another example of the fixed-bed gasification furnace of the present invention. This fixed-bed gasification furnace 201 has substantially the same construction as the fixed-bed gasification furnace of Fig. 17, except that the former is equipped with two gasifying agent supply pipelines. Specifically, this fixed-bed gasification furnace 201 has a gently sloping rotatable conical perforated plate 204 and an inner casing 215 defining an A-compartment 215 (i.e., a volatiles pyrolysis section) above it, within an outer casing 16 constituting the outer wall of fixed-bed gasification furnace 201. Inner casing 215 and outer casing 216 are dimensioned so that the ratio of the cross-sectional area of inner casing 215 to the cross-sectional area of the space between inner casing 215 and outer casing 216 (i.e., a B-compartment 218 constituting a fixed carbon partial combustion/gasification section) is equal to about 1:3. To a space below perforated plate 204, air 223 is supplied through a gasifying agent supply pipeline 205' and a gaseous mixture of oxygen 224 and steam 225 is supplied through a gasifying agent supply pipeline 205". In this furnace, air 223 supplied through gasifying agent supply pipeline 205' is introduced mainly into A-compartment, while the gaseous mixture of oxygen 224 and steam 225 supplied through gasifying agent supply pipeline 205" is introduced mainly into B-compartment.

Using this fixed-bed gasification furnace 201, the same scrap tires as used in Example 7 were subjected to a gasification test. Scrap tires 220, which had been cut into pieces, were fed to the upper part of A-compartment 217 within inner casing 215 through a charging chute 219. These scrap tires 220 were heated by a fixed carbon combustion gas 213 produced in the lower part of A-compartment 217 as a result of the partial combustion of a portion of the fixed carbon present in residue 221 with the aid of air 223 supplied as a gasifying agent, so that volatiles present therein were pyrolyzed and gasified to produce a volatiles-gasified gas 208. A portion of the resulting residue (consisting largely of fixed carbon) 221 is burned, while the remainder moved to B-compartment 218 with the rotation of perforated plate 204, and was partially burned and gasified with the aid of the gaseous mixture of oxygen 224 and steam 225 supplied as a gasifying agent. Thus, a fixed carbon-gasified gas 209 containing combustible components such as CO and H₂ was produced. This fixed carbon-gasified gas 209 was mixed with volatiles-gasified gas 208 in the upper part of the gasification furnace to produce a scrap tire-gasified gas 222.

When air 223 was supplied to A-compartment 217 at a molar equivalent ratio of 0.3 based on the fixed carbon (about 30% by weight) present in scrap tires 220 (i.e., 0.8 Nm³ of air per kg of scrap tire), about a half of the fixed carbon was burned to produce a fixed carbon-gasified gas 213 containing CO, CO₂ and the like in addition to N₂ and having a temperature of about 1,000°C. Scrap tires 220 were heated by this fixed carbon-gasified gas 213, so that volatiles are pyrolyzed at about 500°C to produce a volatiles-gasified gas 208 containing high-molecular hydrocarbons. On the other hand, the fixed carbon remaining in residue 221 was partially burned and gasified in B-compartment 218 with a gaseous mixture of oxygen 224 and steam 225 containing oxygen and steam at molar equivalent ratios of 0.4 and 1.2, respectively (i.e., 0.11 Nm³ of oxygen and 0.34 Nm³ of steam per kg of scrap tire). Thus, there was obtained a fixed carbon-gasified gas 209 containing almost equal volumes of CO₂, CO, H₂ and H₂O and having a temperature of about 1,000°C.

The fourth aspect of the present invention is more specifically explained with reference to the following example.

(Example 9)

Fig. 19 is a schematic view illustrating an example of the fixed-bed gasification furnace of the present invention. This fixed-bed gasification furnace 301 has an organic waste charging chute 304 connected to the upper part of a cylindrical gasification furnace casing 302, an organic waste-gasified gas outlet 305 provided at the top thereof, and a perforated plate 303 disposed in the lower part thereof and functioning to hold the organic waste charged thereto and supply a gasifying agent uniformly. To the bottom of gasification furnace casing 302 or its side wall below perforated plate 303 is connected a mixing vessel 306 by way of a pipeline. This mixing vessel 306 serves to prepare a gasifying agent 318 by mixing an oxygen-containing gas 16 and steam 317 supplied through valves 307' and 307'', respectively.

Perforated plate 303 has a gently sloping umbrella-like shape and is mounted rotatably.

This fixed-bed gasification furnace 301 is equipped with an ultrasonic level meter 313 serving as a means for measuring the height of the layer of organic waste fed to the furnace and also with a thermocouple 314 serving as a means for measuring the internal temperature of the gasification furnace. In addition, a controller 315 is installed which controls the degree of opening of valves 307' and 307'' in response to signals from these ultrasonic level meter 313 and thermocouple 314. In Fig. 19, the degree of opening of valves 307' and 307'' are controlled by the single controller 315. However, it is a matter of course that valves 307' and 307'' may be controlled by two separate controllers.

Using this fixed-bed gasification furnace 301, scrap tires providing a typical example of organic waste were subjected to a gasification test.

As shown in Fig. 19, a gasifying agent 318 was prepared by introducing an oxygen-containing gas 316 and steam 317 into a mixing vessel 306 while regulating their feed rates by means of valves 307' and 307'', respectively, and supplied to a space below the rotating perforated plate 303.

Scrap tires (organic waste) 308, which had been cut into chips, were fed through an organic waste charging chute 304, forming a scrap tire layer on perforated plate 303. In a volatiles pyrolysis region 309 corresponding to the upper part of the scrap tire layer, volatiles were pyrolyzed and gasified. The resulting residue 310 consisting largely of fixed carbon moved downward and was partially burned and gasified in a fixed carbon partial combustion/gasification region 311. The gas obtained by the pyrolysis and gasification of volatiles and the gas obtained by the partial combustion and gasification of fixed carbon were mixed together and withdrawn through an organic waste-gasified gas outlet 305 as an organic waste-gasified gas 312.

During this process, the distance (h) between the top of gasification furnace casing 302 and the upper surface of the layer of scrap tires (organic waste) 308 was measured by means of ultrasonic level meter 313. By comparison with the distance (H) between the top of gasification furnace casing 302 and the upper surface of perforated plate 303, the height of the layer of scrap tires (organic waste) 308 was determined as (H-h). In response to the difference between this value and a preset value, controller 315 regulated the feed rate of the oxygen-containing gas by controlling the degree of opening of valve 307'.

Moreover, the internal temperature (T) of the gasification furnace (i.e., the temperature just above the organic waste layer which is almost equal to the temperature of the organic waste-gasified gas) was measured by means of thermocouple 314. In response to the difference between this value and a preset value, controller 315 regulated the feed rate of steam by controlling the degree of opening of valve 307''.

Scrap tires contain 60-70% by weight of volatiles (such as raw rubber and oil), 20-30% by weight of fixed carbon, and 10-15% by weight of inorganic components. In order to adjust the internal temperature of the gasification furnace to 500°C, it is preferable that oxygen be supplied in amount as expressed by a molar equivalent ratio (O₂/C) of 0.4-0.5 based on the fixed carbon present in scrap tires and that steam be supplied in an amount as expressed by a molar equivalent ratio (H₂O/C) of 1.0-1.5 based on the fixed carbon present in scrap tires. In a gasification furnace having a capacity for treating scrap tires at a rate of 1 ton per hour, the feed rates of oxygen and steam are controlled as shown in Fig. 20.

Fig. 20(a) is a graph showing the relationship between the height (H-h) of the scrap tire layer and the oxygen feed rate controlled in response thereto. This graph indicates that the oxygen feed rate is 200 Nm³/h in a steady state (i.e., when the layer height is equal to a preset value) and that the oxygen feed rate is increased as the layer height becomes larger or decreased as the layer height becomes smaller, in response to a deviation from the preset value of the layer height.

Fig. 20(b) is a graph showing the relationship between the internal temperature (T) of the gasification furnace and the steam feed rate controlled in response thereto. This graph indicates that the steam feed rate is 600 Nm³/h when the temperature is equal to a preset value of 500°C and that the steam feed rate is increased as the temperature becomes higher or decreased as the temperature becomes lower, in response to a deviation from the preset value of the temperature.

The fifth aspect of the present invention is more specifically explained with reference to the following example.

(Example 10)

Fig. 21 is a schematic view illustrating an example of the fixed-bed gasification furnace of the present invention. This fixed-bed gasification furnace 401 has an organic waste charging chute 404 connected to the upper part of a cylindrical gasification furnace casing 402, an organic waste-gasified gas outlet 405 provided at the top thereof, and a perforated plate 403 disposed in the lower part thereof and functioning to hold the organic waste charged thereto and supply a gasifying agent uniformly. To the bottom of gasification furnace casing 402 or its side wall below perforated plate 403 is connected a mixing vessel 406 by way of a pipeline and a valve 407. This mixing vessel 406 serves to prepare a gasifying agent 418 by mixing an oxygen-containing gas 416 and steam 417 supplied thereto. Moreover, a nozzle 419 for supplying steam or nitrogen gas to the organic waste layer is provided at a position corresponding to a middle part of the organic waste layer within gasification furnace casing 402. Perforated plate 403 has a gently sloping umbrella-like shape and is mounted rotatably.

This fixed-bed gasification furnace 401 is equipped with an ultrasonic level meter 413 serving as a means for measuring the height of the layer of organic waste fed to the furnace and also with a thermocouple 414 serving as a means for measuring the internal temperature of the gasification furnace. In addition, a controller 415 is installed which controls the degree of opening of valves 407 and 420 in response to signals from these ultrasonic level meter 413 and thermocouple 414. In Fig. 21, the degree of opening of valves 407 and 420 are controlled by the single controller 415. However, it is a matter of course that valves 407 and 420 may be controlled by two separate controllers.

Using this fixed-bed gasification furnace 401, scrap tires providing a typical example of organic waste were subjected to a gasification test.

As shown in Fig. 21, a gasifying agent 418 was prepared by introducing oxygen as an oxygen-containing gas 416 and steam 417 into a mixing vessel 406 and mixing them at a ratio of 1:1, and supplied to a space below the rotating perforated plate 403 at a feed rate regulated by means of valve 407.

Scrap tires (organic waste) 408, which had been cut into pieces, were fed through an organic waste charging chute 404, forming a scrap tire layer on perforated plate 403. In a volatiles pyrolysis region 409 corresponding to the upper part of the scrap tire layer, volatiles were pyrolyzed and gasified. The resulting residue 410 consisting largely of fixed carbon moved downward and was partially burned and gasified in a fixed carbon partial combustion/gasification region 411. Just above this fixed carbon partial combustion/gasification region 411, nitrogen 421 was supplied through nozzle 419 at a feed rate regulated by means of a valve 420 so that the temperature of volatiles pyrolysis region 409 would be in the range of 500 to 700°C. The gas obtained by the pyrolysis and gasification of volatiles and the gas obtained by the partial combustion and gasification of fixed carbon were mixed together and withdrawn through an organic waste-gasified gas outlet 405 as an organic waste-gasified gas 412.

During this process, the distance (h) between the top of gasification furnace casing 402 and the upper surface of the layer of scrap tires (organic waste) 408 was measured by means of ultrasonic level meter 413. By comparison with the distance (H) between the top of gasification furnace casing 402 and the upper surface of perforated plate 403, the height of the layer of scrap tires (organic waste) 408 was determined as (H-h). In response to the difference between this value and a preset value, controller 415 regulated the feed rate of the gasifying agent 418 by controlling the degree of opening of valve 407.

Moreover, the internal temperature (T) of the gasification furnace (i.e., the temperature above the volatiles pyrolysis region which is almost equal to the temperature of the organic waste-gasified gas) was measured by means of thermocouple 414. In response to the difference between this value and a preset value, controller 415 regulated the feed rate of nitrogen by controlling the degree of opening of valve 420.

Scrap tires contain 60-70% by weight of volatiles (such as raw rubber and oil), 20-30% by weight of fixed carbon, and 10-15% by weight of inorganic components. In order to adjust the temperature of organic waste-gasified gas 412 (i.e., the temperature just above the organic waste layer) to 500°C, oxygen and steam forming a gasifying agent should be supplied in amounts as expressed by molar equivalent ratios (O_2/C and H_2O/C) of 0.4-0.5 based on the fixed carbon present in scrap tires, and nitrogen should be supplied in an amount as expressed by a molar ratio (N_2/C) of about 0.5 based on the fixed carbon present in scrap tires. In a gasification furnace having a capacity for treating scrap tires at a rate of 1 ton per hour, the feed rates of the gasifying agent and nitrogen are controlled as shown in Fig. 22.

Fig. 22(a) is a graph showing the relationship between the height (H-h) of the scrap tire layer and the gasifying agent feed rate controlled in response thereto. This graph indicates that the gasifying agent feed rate is 400 Nm³/h in a steady state (i.e., when the layer height is equal to a preset value) and that the feed rate of oxygen is increased as the layer height becomes larger or decreased as the layer height becomes smaller, in response to a deviation from the preset value of the layer height.

Fig. 22(b) is a graph showing the relationship between the internal temperature (T) of the gasification furnace and the nitrogen feed rate controlled in response thereto. This graph indicates that the steam feed rate is 200 Nm³/h when the temperature is equal to a preset value of 500°C and that the nitrogen feed rate is increased as the temperature becomes higher or decreased as the temperature becomes lower, in response to a deviation from the preset value of the temperature.

The sixth aspect of the present invention is more specifically explained with reference to the following example.

(Example 11)

Fig. 23 is a schematic view illustrating an example of the fixed-bed gasification furnace of the present invention. This fixed-bed gasification furnace 501 has a gently sloping rotatable conical perforated plate 504 and an inner casing 502 defining an A-compartment 505 above it, within an outer casing 503 constituting the outer wall of fixed-bed gasification furnace 501. Inner casing 502 and outer casing 503 are dimensioned so that the ratio of the cross-sectional area of inner casing 502 to the cross-sectional area of the space between inner casing 502 and outer casing 503 (i.e., B-compartment 506) is equal to about 1:1. Correspondingly to A-compartment 505 and B-compartment 506, the space below perforated plate 504 is also divided into an A1-compartment 507 and B1-compartment 508. Air 509 is supplied to A1-compartment 507 through a valve 511, while a gaseous mixture 510 of oxygen and steam is supplied to B1-compartment 508 through a valve 512.

This fixed-bed gasification furnace 501 is equipped with ultrasonic level meters 513 and 514 serving as means for measuring the height of the layer of organic waste 525 in A-compartment 505 and the height of the layer of residue 526 in B-compartment 506, respectively, and also with a thermocouple 515 serving as a means for measuring the internal temperature of A-compartment 505. In response to signals from these ultrasonic level meters 513, 514 and thermocouple 515, a controller 516 controls the degree of opening of valves 511 and 512, as well as a variable-speed drive 519, connected directly with a motor 520 for rotating perforated plate 504. In Fig. 23, the degrees of opening of valves 511, 512 and variable-speed drive 519 are controlled by the single controller 516. However, it is a matter of course that valves 511, 512 and variable-speed drive 519 may be controlled by separate controllers.

Using this fixed-bed gasification furnace 501, scrap tires (composed of 70% of volatiles and 30% of fixed carbon) providing a typical example of organic waste were subjected to a gasification test.

Scrap tires (organic waste) 521, which had been cut into pieces, were fed to A-compartment through a charging hole 523 by means of a feeder 522, forming a scrap tire layer on perforated plate 504. In a volatiles pyrolysis region 523 corresponding to the upper part of the scrap tire layer, volatiles were pyrolyzed and gasified. The resulting residue 523 consisting largely of fixed carbon moved downward and a portion thereof was partially burned and gasified in a fixed carbon partial combustion region 524 with air 509 supplied from A1-compartment 507. The remainder moved to B-compartment 506 with the rotation of perforated plate 504 and was partially burned and gasified with the gaseous mixture 510 of oxygen and steam supplied as a gasifying agent from B1-compartment 508. The gas obtained by the pyrolysis and gasification of volatiles and the gas obtained by the partial combustion and gasification of fixed carbon were mixed together and withdrawn from the gasification furnace as an organic waste-gasified gas 527.

During this process, the internal temperature (T) of A-compartment 505 (i.e., the temperature just above the organic waste layer which is almost equal to the temperature of the organic waste-gasified gas) was measured by means of thermocouple 515. In response to the difference between the measured value and a preset value (e.g., 500°C), controller 516 regulated the amount of air 509 supplied to A1-compartment 507 by controlling valve 511.

Moreover, the distance (h1) between the top of gasification furnace 501 and the upper surface of the layer of scrap tires (organic waste) 525 in A-compartment 505 was measured by means of ultrasonic level meter 513. By comparison with the distance (H) between the top of gasification furnace 501 and the upper surface of perforated plate 504, the height of the layer of scrap tires (organic waste) 525 was determined as (H-h1). In response to the difference between this value and a preset value, controller 516 regulated the amount of gaseous mixture 510 supplied to B1-compartment 508 by controlling valve 512.

Furthermore, the distance (h2) between the top of gasification furnace 501 and the upper surface of the layer of residue 526 in B-compartment 506 was measured by means of ultrasonic level meter 514. By comparison with the distance (H) between the top of gasification furnace 501 and the upper surface of perforated plate 504, the height of the layer of residue 526 was determined as (H-h2). In response to the difference between this value and a preset value, controller 516 regulated the rotational speed of perforated plate 504 by means of a mechanical variable-speed drive 519. Thus, the rate of movement of residue 526 from A-compartment 505 to B-compartment 506 could be regulated.

50 **Claims**

1. A process for production of carbon black which comprises the steps of:
partially burning and gasifying organic waste in a gaseous mixture of an oxygen-containing gas and steam with an equivalent ratio of oxygen being 1 or less;
partially burning a resulting combustible gas at a temperature of 1,000°C or above in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen; and
quenching the resulting partial combustion gas having a temperature of 1,000°C or above to 700°C or below in an inert atmosphere.

2. A process for production of carbon black which comprises the steps of:
 pyrolyzing and gasifying organic waste at a temperature of 500°C or above in an oxygen-free environment;
 partially burning a resulting combustible gas at a temperature of 1,000°C or above in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen; and
 quenching the resulting partial combustion gas having a temperature of 1,000°C or above to 700°C or below in an inert atmosphere.

3. A system for the production of carbon black from organic waste which comprises:
 gasification means either for partially burning and gasifying organic waste in a gaseous mixture of an oxygen-containing gas and steam with an equivalent ratio of oxygen being 1 or less or for pyrolyzing and gasifying organic waste at a temperature of 500°C or above in an oxygen-free environment;
 a combustion furnace for partially burning a combustible gas obtained by said gasification means at a temperature of 1,000°C or above in an oxygen-deficient environment containing less than a stoichiometric amount of oxygen;
 quenching means for quenching the partial combustion gas leaving said combustion furnace and having a temperature of 1,000°C or above to 700°C or below by means of either water or nitrogen;
 collector for separating and collecting formed carbon black; and
 an exhaust gas treating apparatus for subjecting exhaust gas obtained after separation of carbon black to pollution control treatments.

4. A method for combustion of organic waste which comprises burning organic waste in a combustion furnace with a combustion-support gas which is either a mixture of air and steam or a mixture of air, steam and combustion exhaust gas and which has an oxygen concentration of 10 to 21%.

5. A method for combustion of organic waste which comprises passing combustion exhaust gas produced by the method of claim 4 through a heat exchanger to recover thermal energy therefrom in a form of steam, and using a portion of a resulting steam for the combustion-support gas to be fed to the combustion furnace.

6. A fixed-bed gasification furnace wherein a gasifying agent comprising an oxygen-containing gas is supplied to said furnace charged with organic waste, volatiles present in the organic waste are pyrolyzed and gasified in an upper part of said furnace, residual fixed carbon is gasified by reaction with the gasifying agent in a lower part of said furnace, and the residual fixed carbon also serves to supply heat for pyrolysis of the volatiles,
 said furnace comprises two divided internal sections: a volatiles pyrolysis section for gasifying a portion of the residual fixed carbon by reaction with the gasifying agent and for pyrolyzing and gasifying the volatiles by heat so evolved; and a fixed carbon partial combustion/gasification section for reacting surplus fixed carbon with the gasifying agent.

7. A fixed-bed gasification furnace wherein a gasifying agent comprising an oxygen-containing gas is supplied to said furnace charged with organic waste, volatiles present in the organic waste are pyrolyzed and gasified in an upper part of said furnace, residual fixed carbon is gasified by reaction with the gasifying agent in the lower part of said furnace, and the residual fixed carbon also serves to supply heat for pyrolysis of the volatiles,
 said furnace comprising:
 two divided internal sections: a volatiles pyrolysis section for gasifying a portion of the residual fixed carbon by reaction with the gasifying agent and for pyrolyzing and gasifying the volatiles by heat so evolved, and a fixed carbon partial combustion/gasification section for reacting surplus fixed carbon with the gasifying agent;
 a first pipeline for supplying a first gasifying agent mainly to said volatiles pyrolysis section; and
 a second pipeline for supplying a second gasifying agent mainly to said fixed carbon partial combustion/gasification section, so as to allow the compositions and feed rates of the first and second gasifying agents to be controlled independently.

8. A method for the gasification of organic waste which comprises the steps of:
 providing a fixed-bed gasification furnace which comprises two divided internal sections: a volatiles pyrolysis section for gasifying a portion of residual fixed carbon by reaction with a gasifying agent and for pyrolyzing and gasifying volatiles by heat so evolved, and a fixed carbon partial combustion/gasification section for reacting only surplus fixed carbon with the gasifying agent;
 feeding organic waste to said furnace; and
 controlling a composition and feed rate of the gasifying agent for gasification of the organic waste, so that a temperature of said volatiles pyrolysis section is in a range of 500 to 700°C and a temperature of said fixed carbon partial combustion/gasification section is in a range of 700 to 1,500°C.

9. A fixed-bed gasification furnace wherein organic waste charged thereinto is gasified with a supply of a gasifying agent comprising a mixture of an oxygen-containing gas and steam, said furnace comprising means for measuring a height of a layer of the charged organic waste in said furnace, means for measuring an internal temperature of said furnace, a controller for controlling a feed rate of the oxygen-containing gas in response to a signal from said means for measuring the height of the organic waste layer, and a controller for controlling a feed rate of steam in response to a signal from said means for measuring the internal temperature of said furnace.

10. A method for gasifying organic waste by charging an organic waste into a fixed-bed gasification furnace and gasifying the organic waste with supply of a gasifying agent comprising a mixture of an oxygen-containing gas and steam, said method comprising the steps of: controlling a feed rate of the oxygen-containing gas in response to a height of a layer of the charged organic waste in said furnace, and controlling a feed rate of steam in response to an internal temperature of said furnace, so as to carry out the gasification.

11. A fixed-bed gasification furnace wherein organic waste charged thereinto is gasified with supply of a gasifying agent comprising a mixture of an oxygen-containing gas and steam, said furnace comprising means for measuring a height of a layer of the charged organic waste in said furnace, means for measuring an internal temperature of said furnace, a nozzle for supplying steam or nitrogen gas to a middle part of the organic waste layer, a controller for controlling a feed rate of the gasifying agent in response to a signal from said means for measuring the height of the organic waste layer, and a controller for controlling a feed rate of steam or nitrogen gas from said nozzle in response to a signal from said means for measuring the internal temperature of said furnace.

12. A method for gasifying organic waste by charging the organic waste into a fixed-bed gasification furnace and gasifying the organic waste with supply of a gasifying agent comprising a mixture of an oxygen-containing gas and steam, said method comprising the steps of: supplying either steam or nitrogen gas to a middle part of a layer of fed organic waste in said furnace; controlling a feed rate of the gasifying agent in response to a height of the organic waste layer; and controlling a feed rate of steam or nitrogen gas supplied to a middle part of the organic waste layer in response to an internal temperature of said furnace, so as to carry out the gasification of the organic waste.

13. A fixed-bed gasification furnace wherein organic waste charged thereinto is gasified with a gasifying agent supplied thereto, said furnace comprising:
 two internal sections: an A-compartment where a raw material is fed and volatiles present therein are predominantly pyrolyzed and gasified, and a B-compartment where a residue consisting largely of fixed carbon which remains after most of the volatiles have been pyrolyzed and gasified is introduced and burned or gasified;
 means for detecting an internal temperature of the A-compartment and controlling a feed rate of the gasifying agent supplied to the A-compartment in response to a measured value thereof;
 means for detecting a height of an organic waste layer in the A-compartment and controlling a feed rate of the gasifying agent supplied to the B-compartment in response to a measured value thereof; and
 means for detecting a height of a residue layer in the B-compartment and controlling an amount of residue introduced from the A-compartment into the B-compartment in response to a measured value thereof.

14. A method for gasifying organic waste by charging the organic waste into a fixed-bed gasification furnace and gasifying the organic waste with a gasifying agent supplied to said furnace, said method comprising the steps of: using a fixed-bed gasification furnace comprising two divided internal sections: an A-compartment where a raw material is fed and volatiles present therein are predominantly pyrolyzed and gasified, and a B-compartment where a residue consisting largely of fixed carbon which remains after most of the volatiles have been pyrolyzed and gasified, is introduced and burned or gasified; detecting an internal temperature of the A-compartment; controlling a feed rate of the gasifying agent supplied to the A-compartment in response to a measured value thereof; detecting a height of an organic waste layer in the A-compartment and controlling a feed rate of the gasifying agent supplied to the B-compartment in response to a measured value thereof; detecting a height of a residue layer in the B-compartment; and controlling an amount of residue introduced from the A-compartment into the B-compartment in response to the measured value thereof, so as to carry out the gasification of the organic waste.

FIG. 1

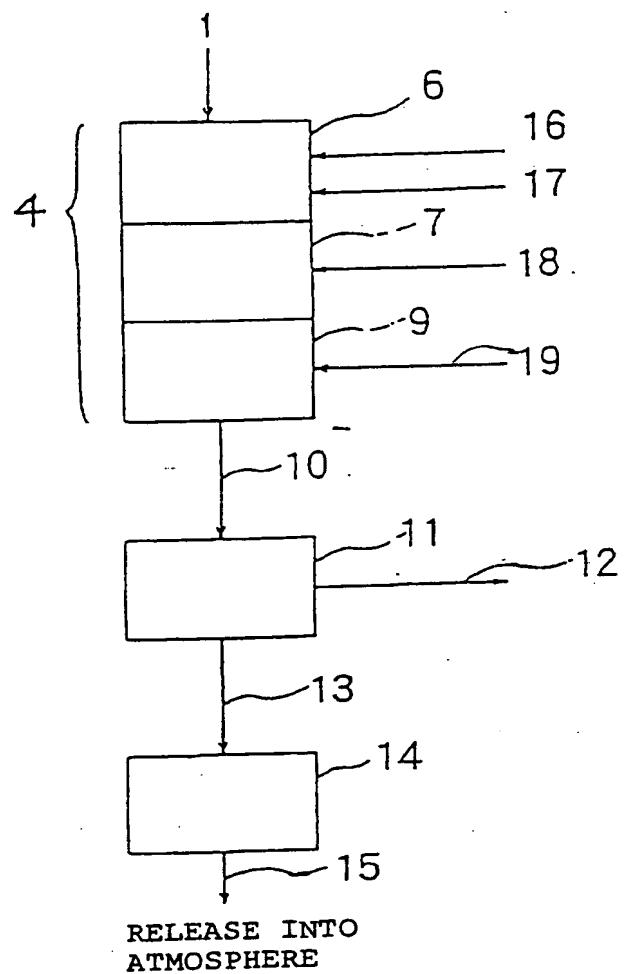


FIG. 2

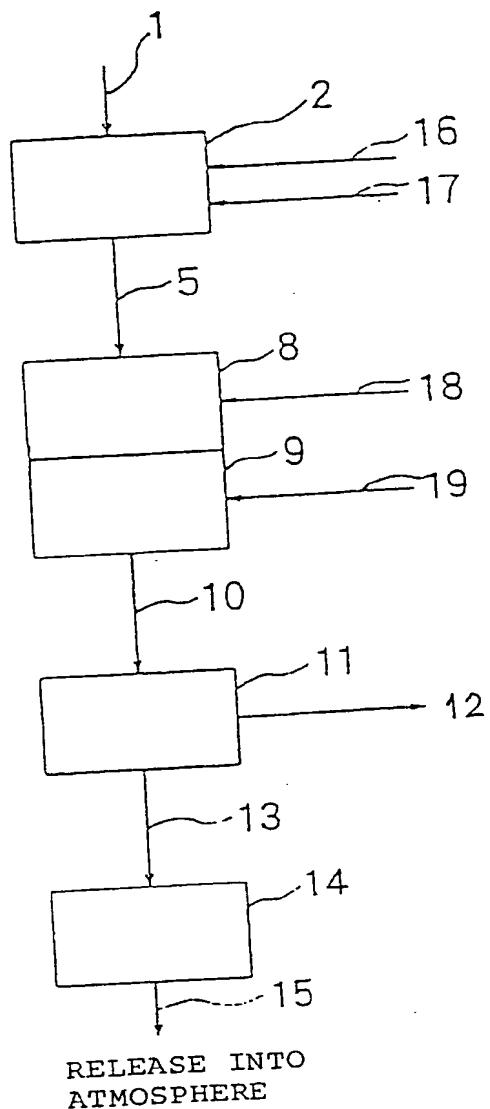
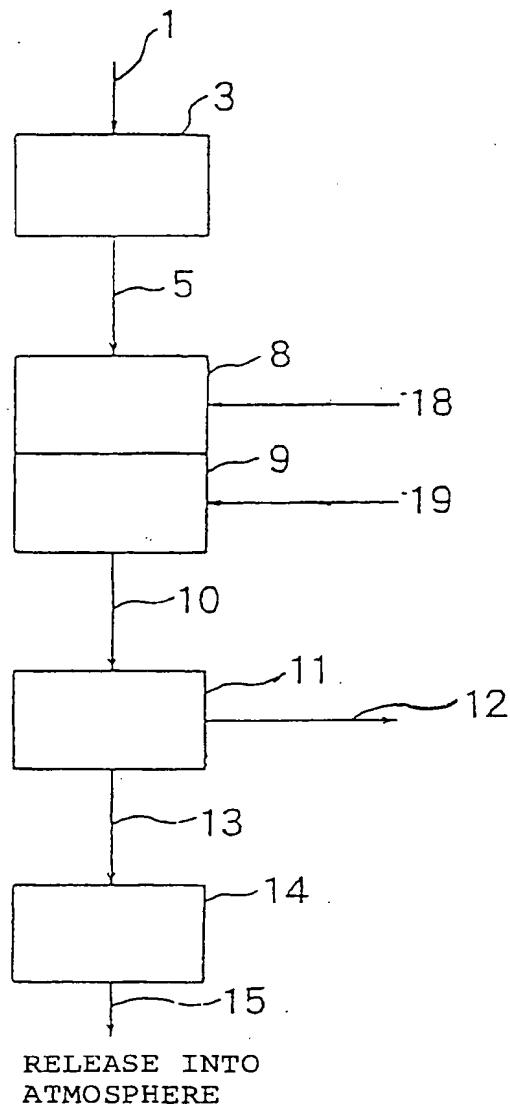


FIG. 3



η : YIELD OF CARBONBLACK
AFTER FIXATION AND
COMBUSTION OF CARBON

FIG. 4

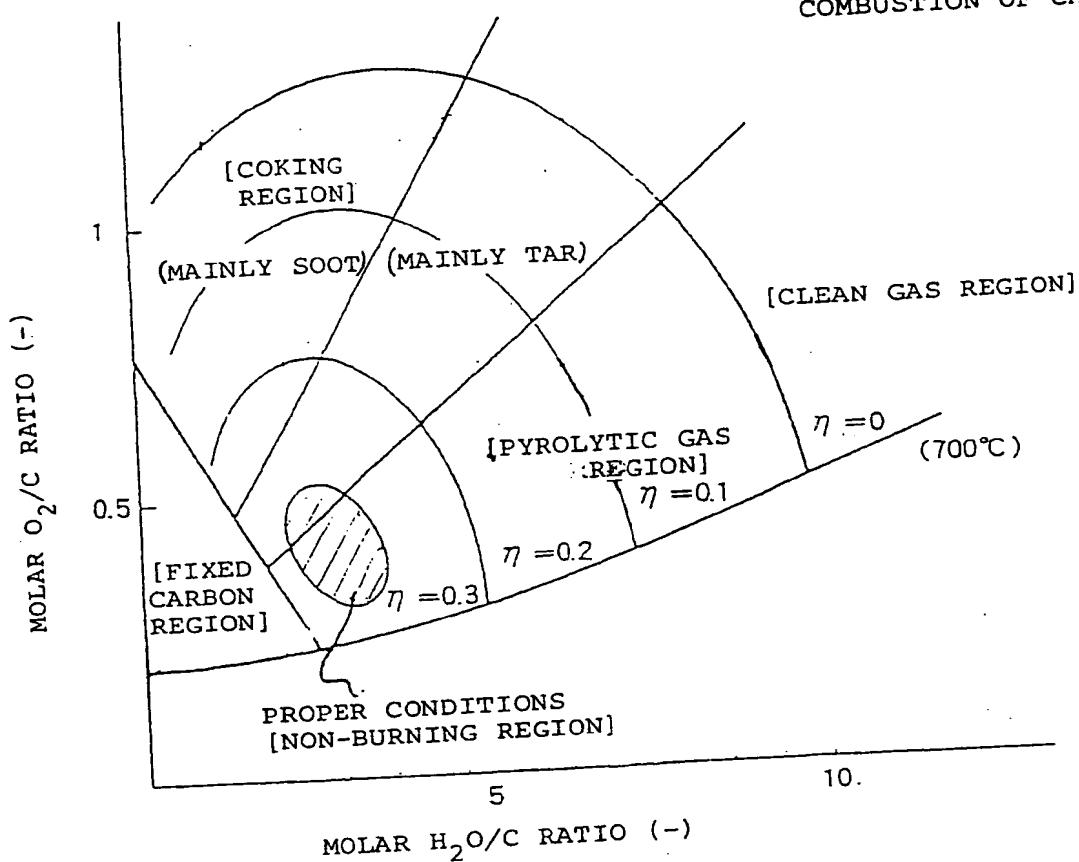


FIG. 5

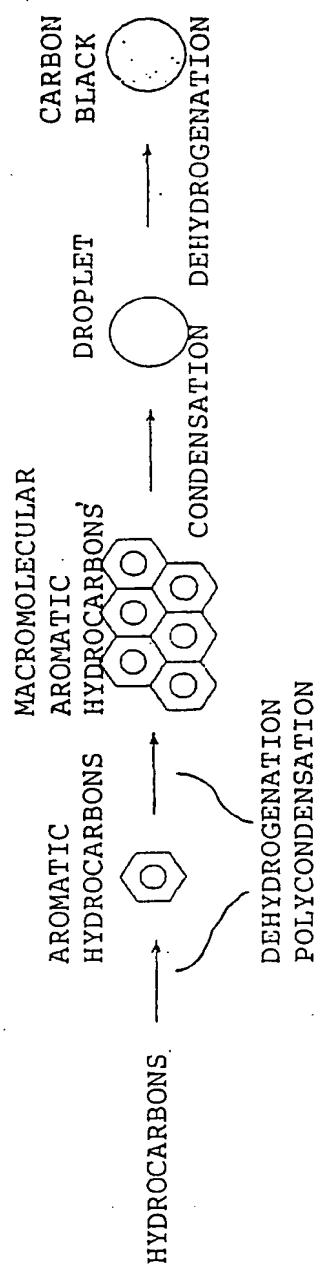


FIG. 6

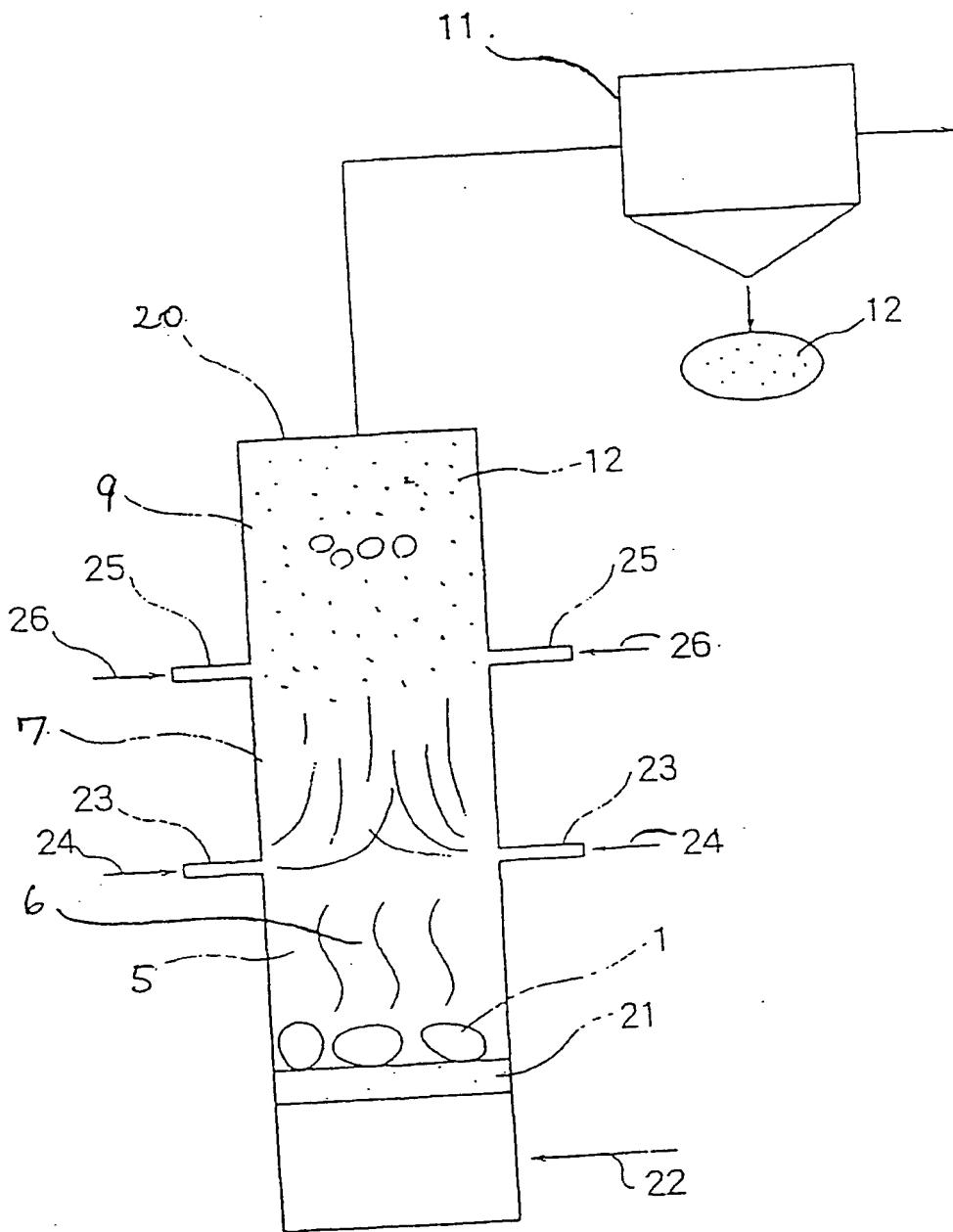


FIG. 7

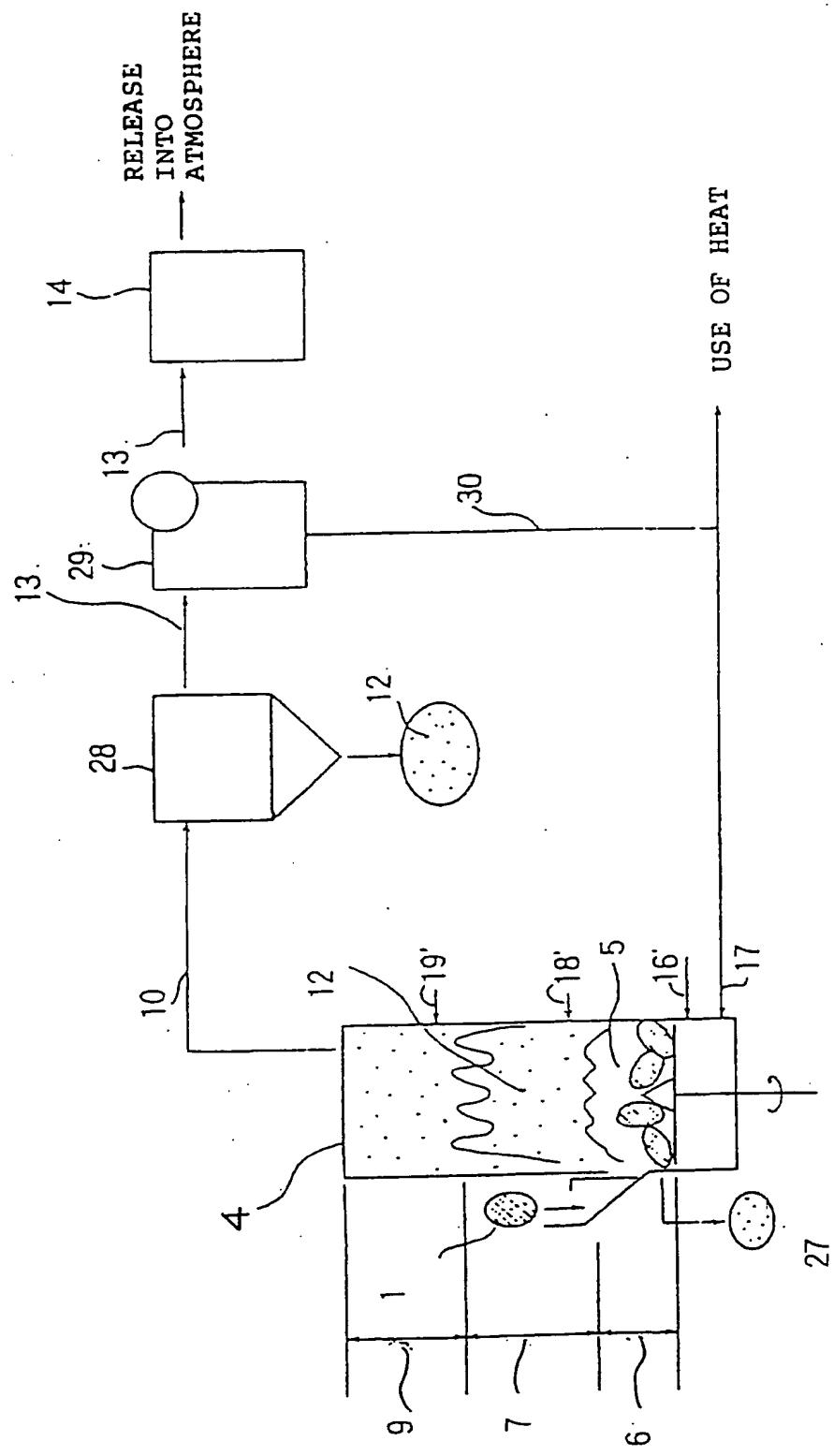


FIG. 8

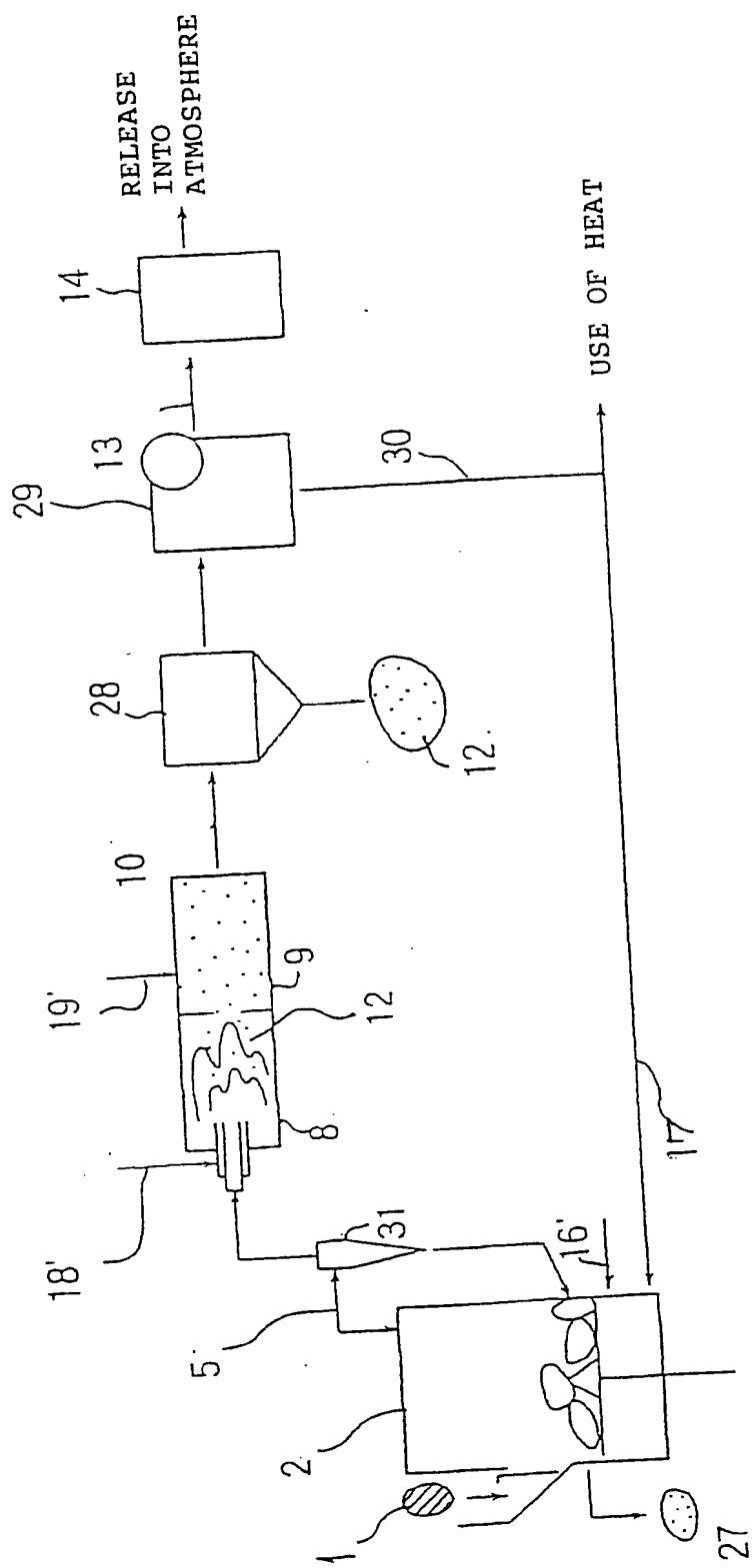


FIG. 9

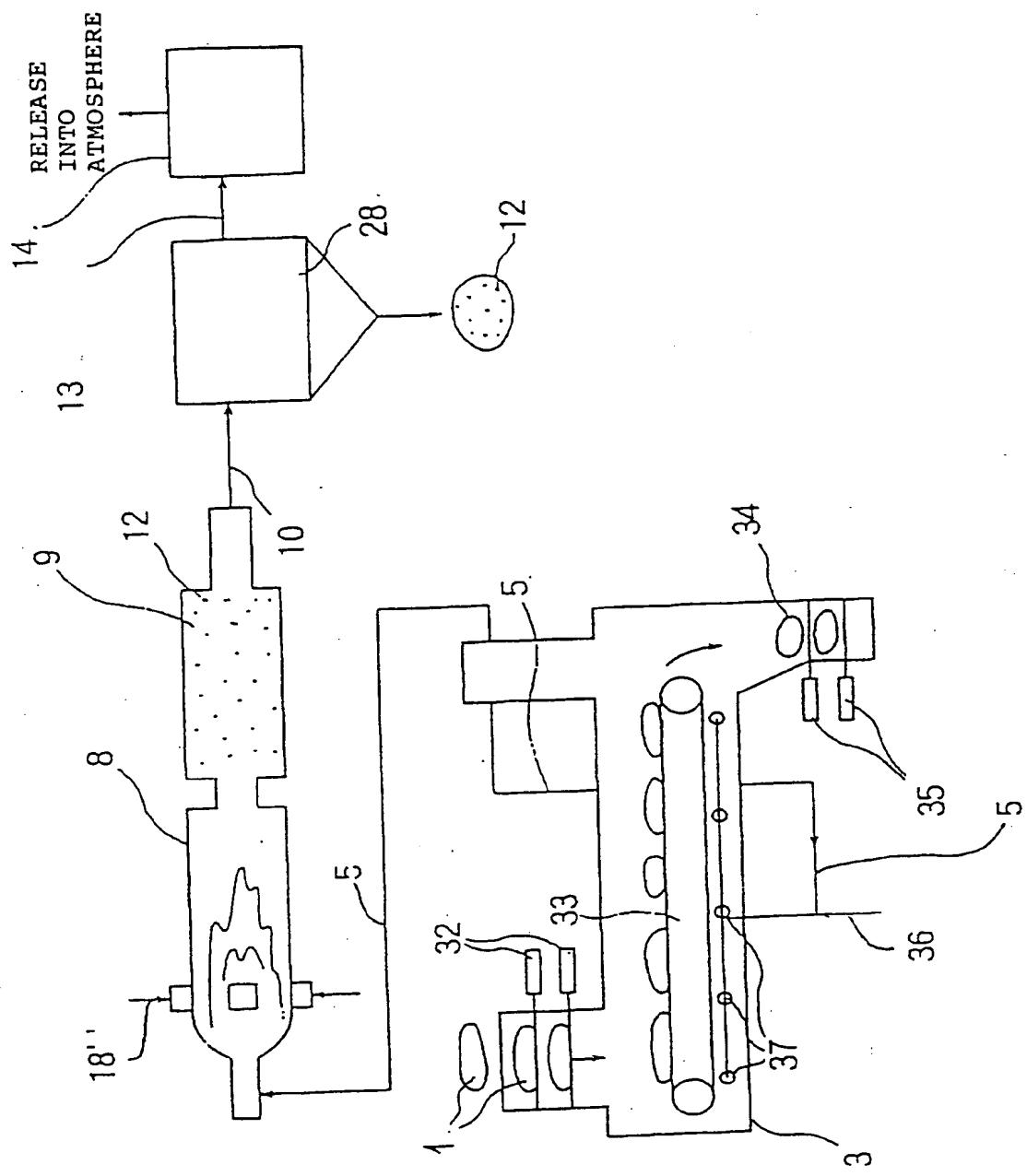


FIG. 10

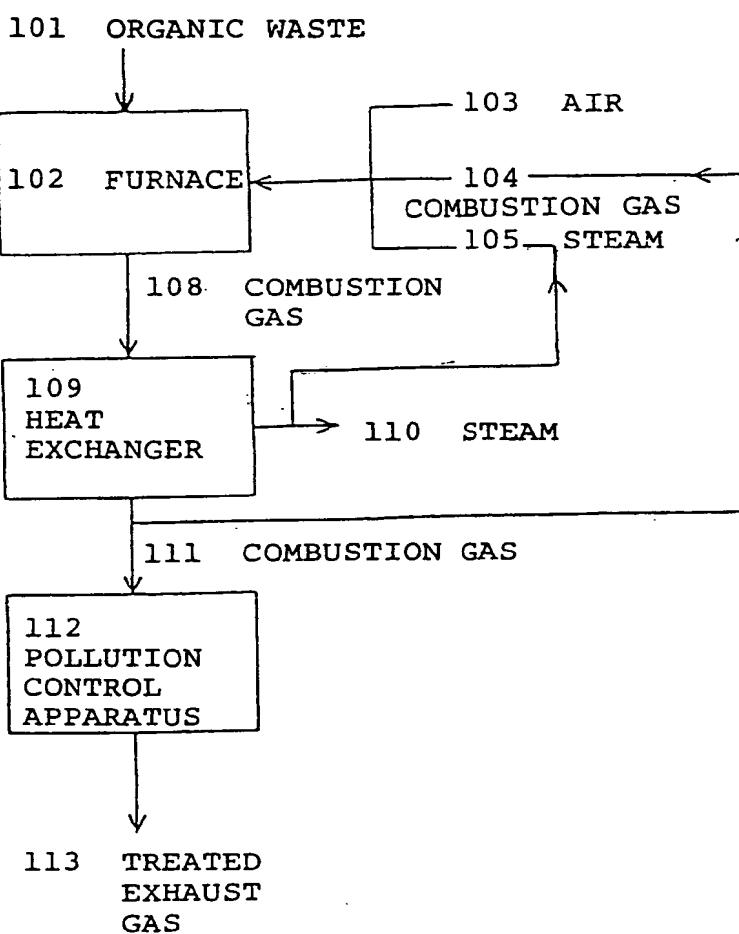


FIG. 11

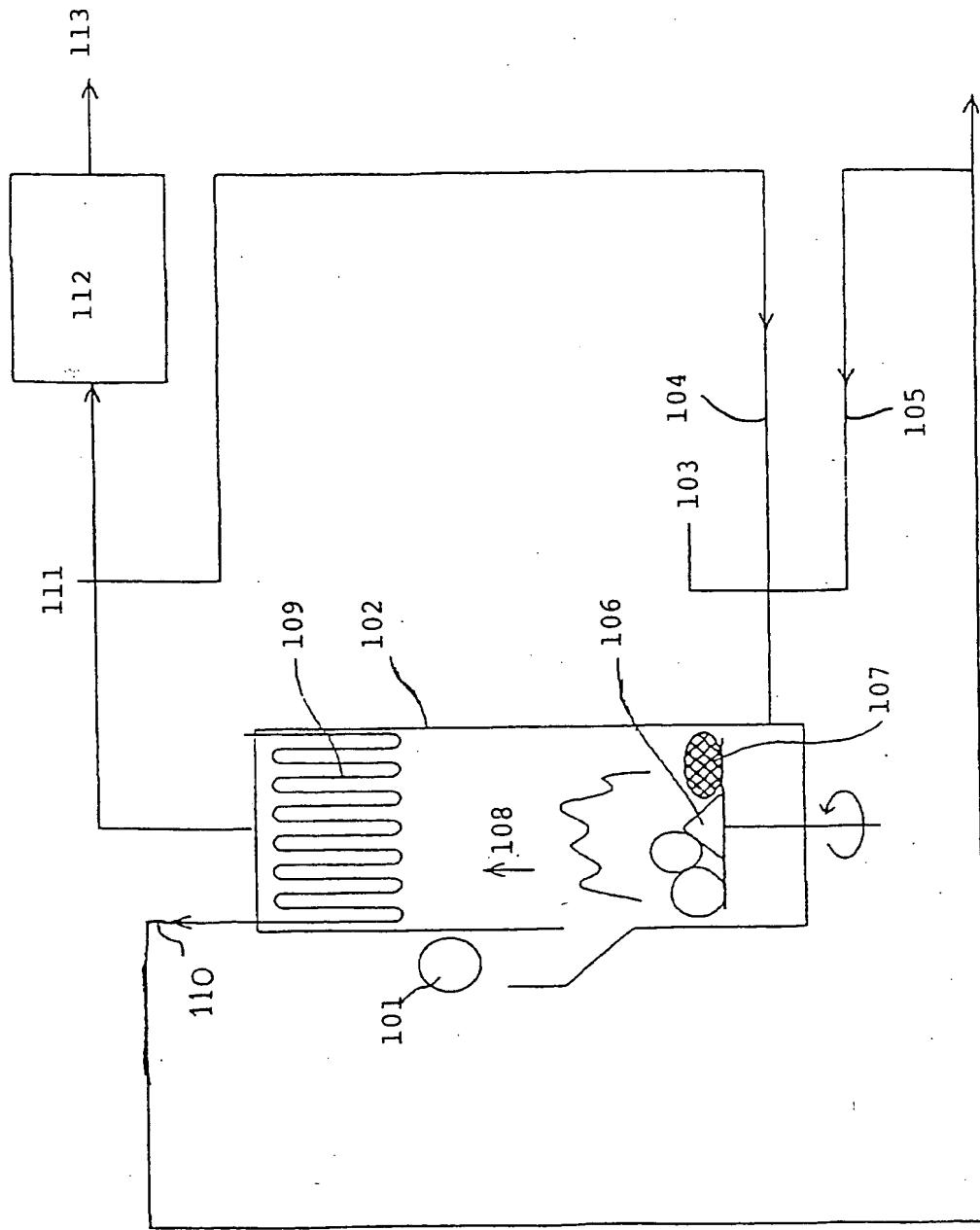


FIG. 12

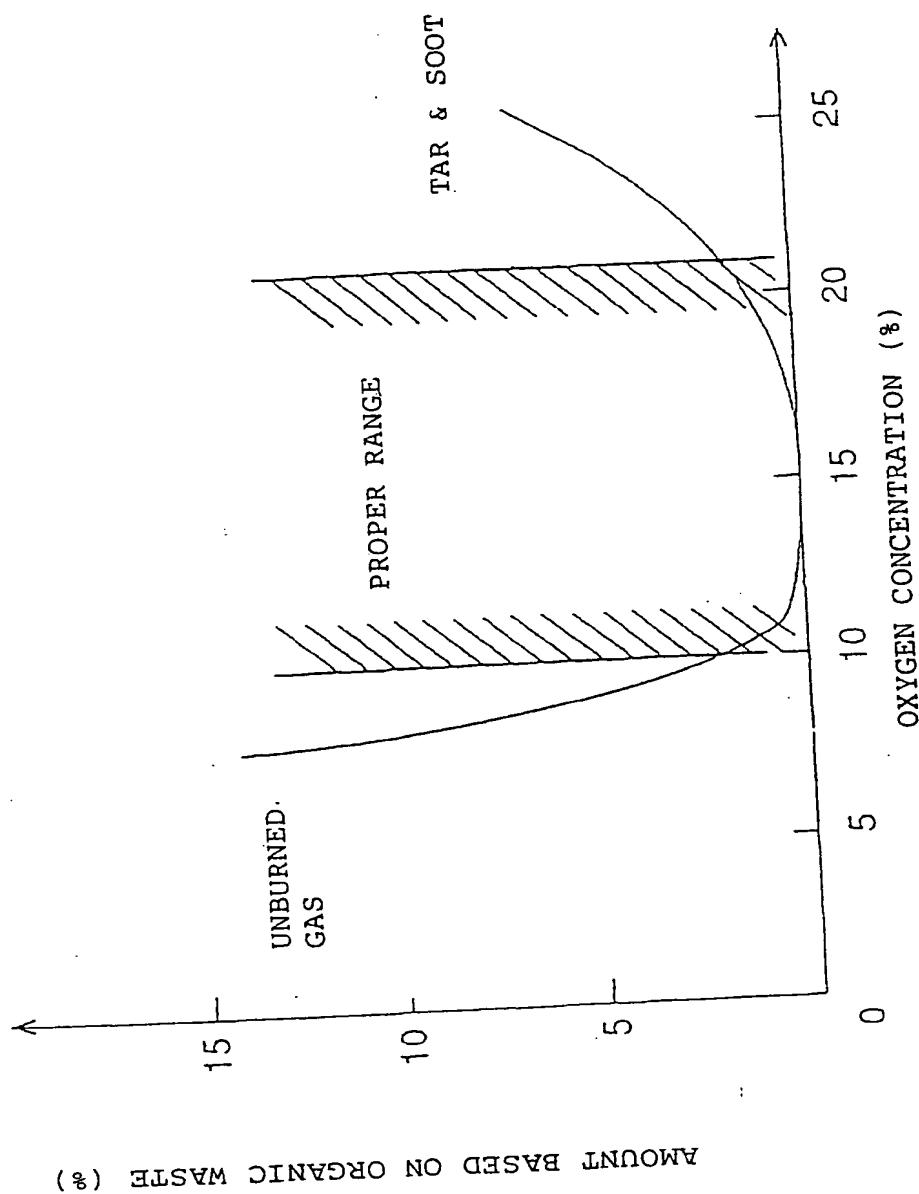


FIG. 13

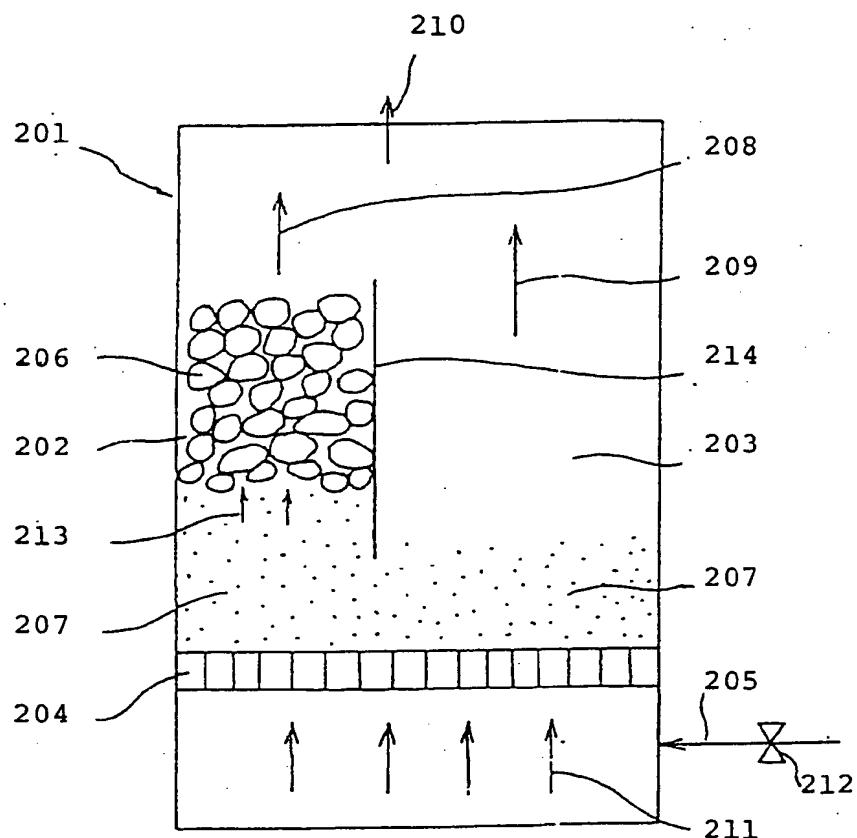


FIG. 14

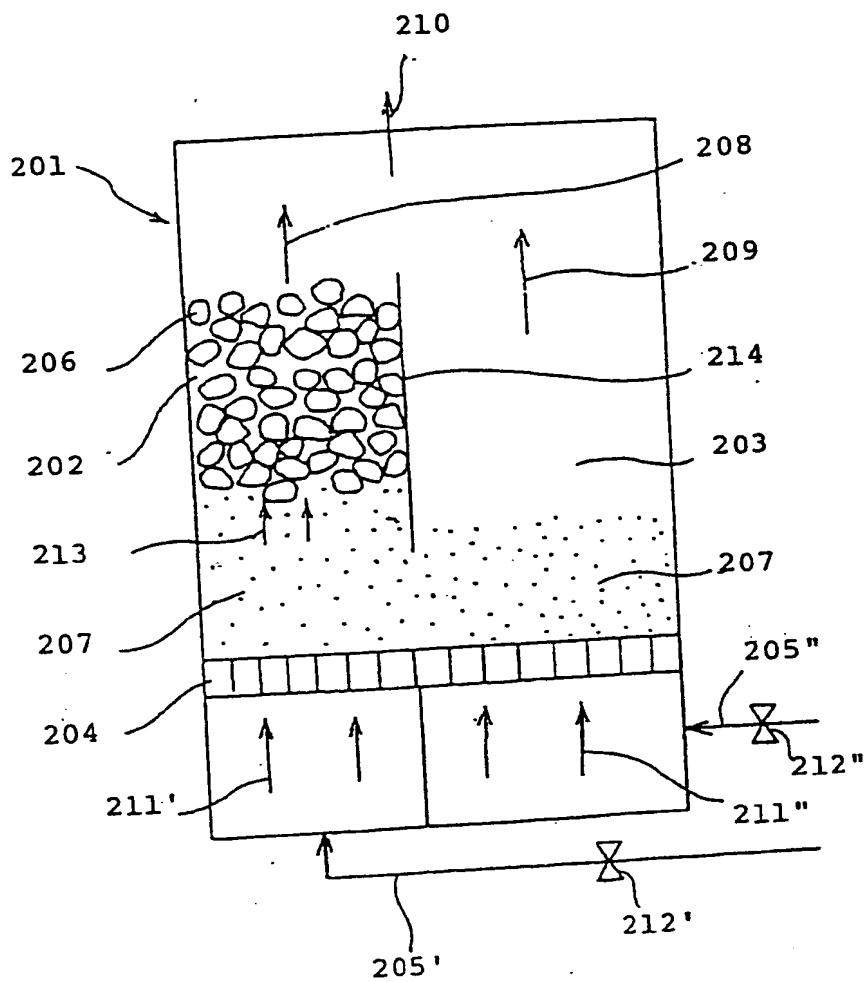


FIG. 15

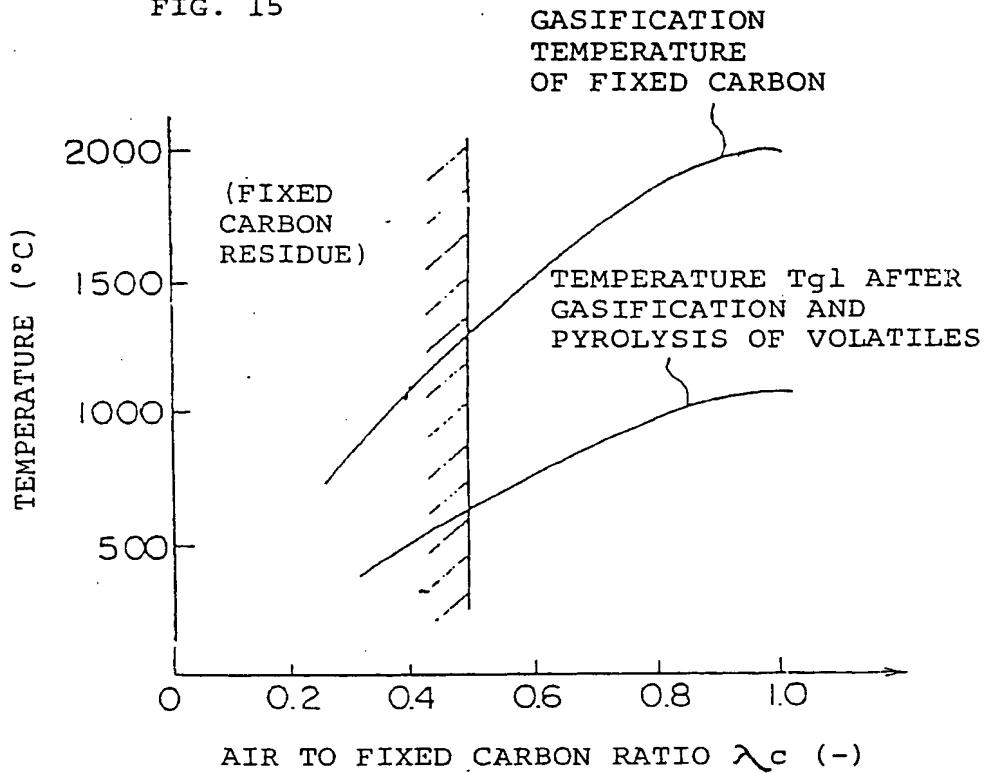


FIG. 16

WHEN $\lambda_c = 0.6$

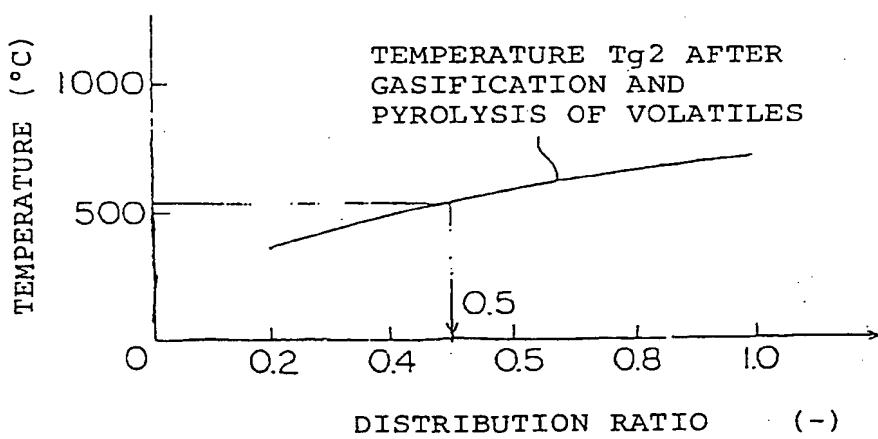


FIG. 17

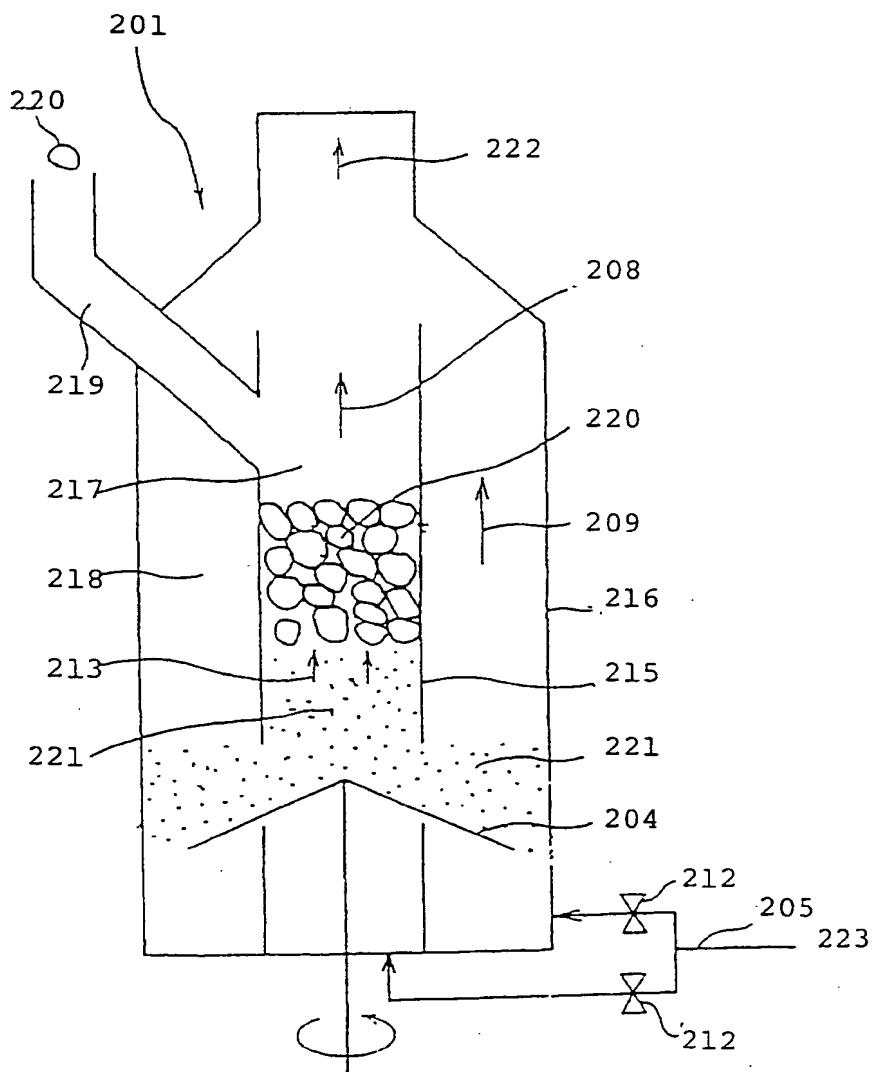


FIG. 18

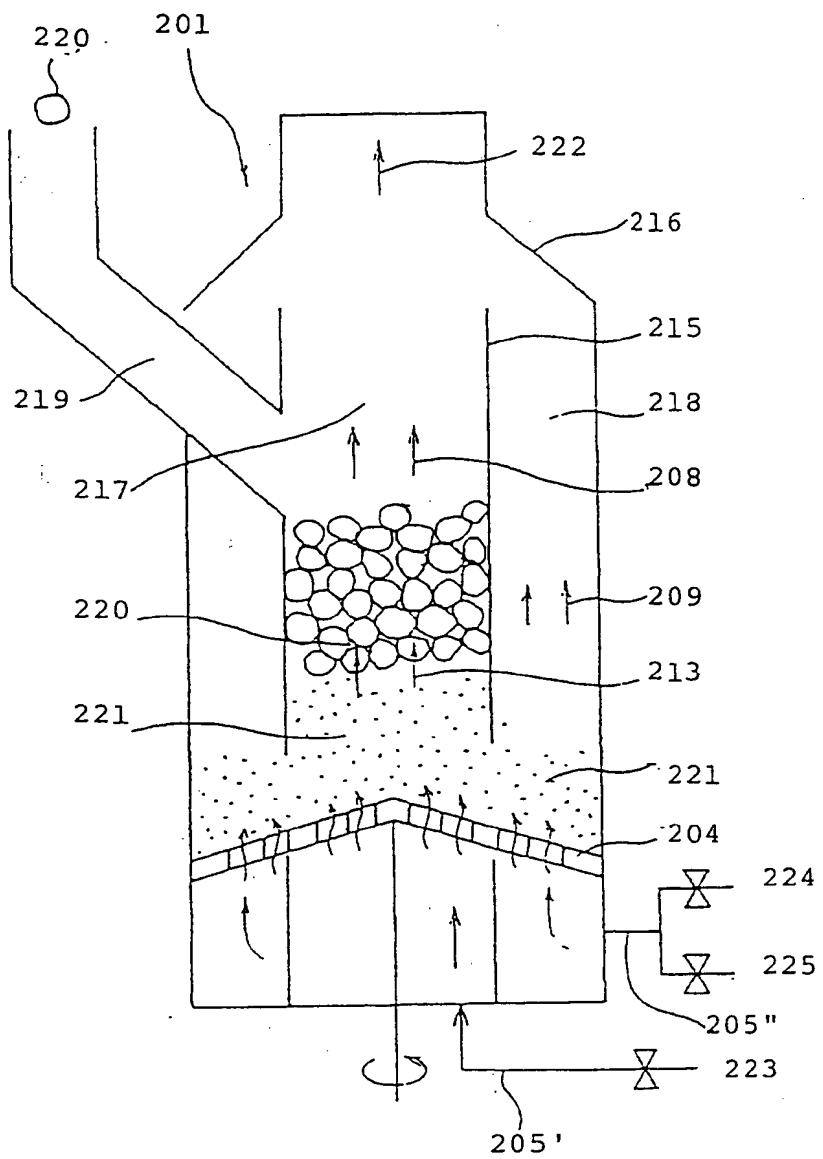


FIG. 19

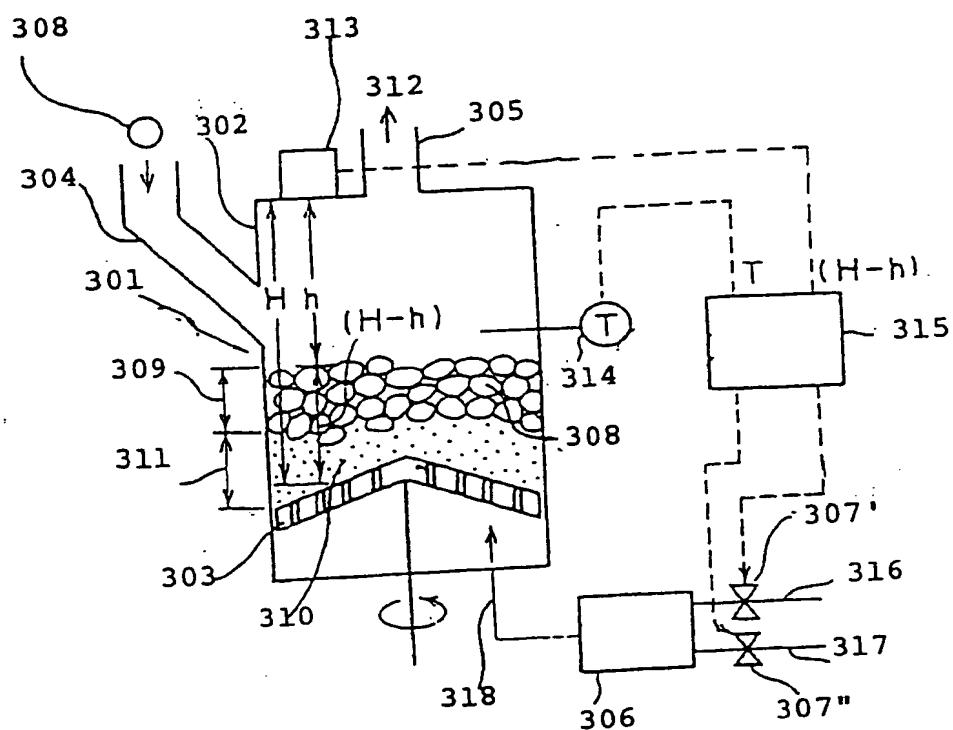


FIG. 20 (a)

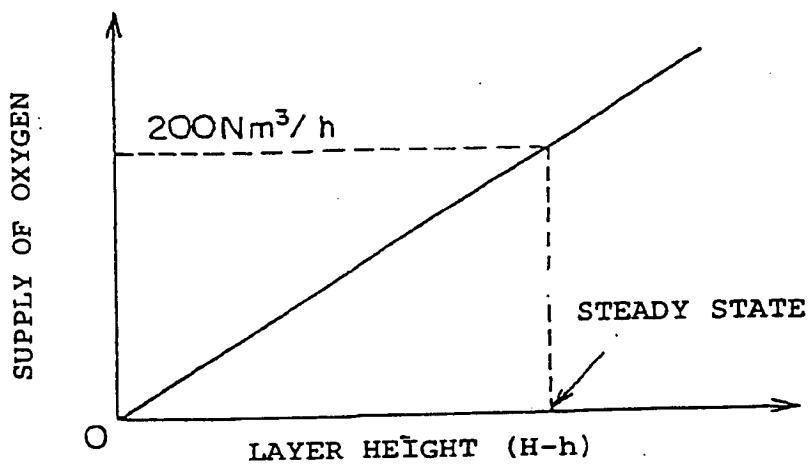


FIG. 20 (b)

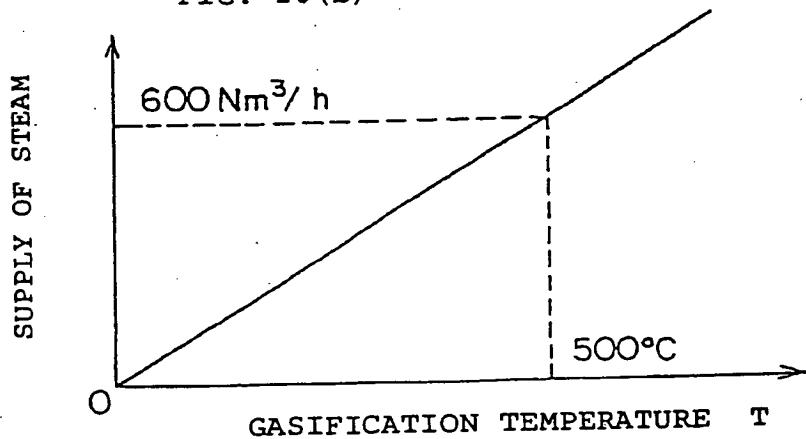


FIG. 21

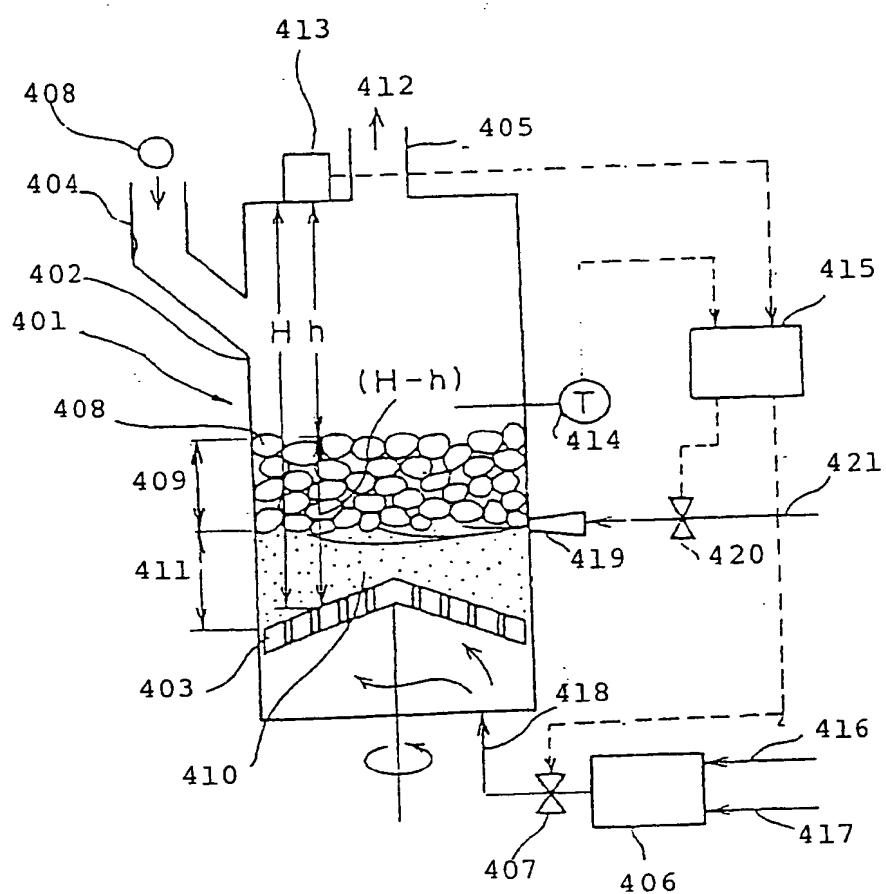


FIG. 22 (a)

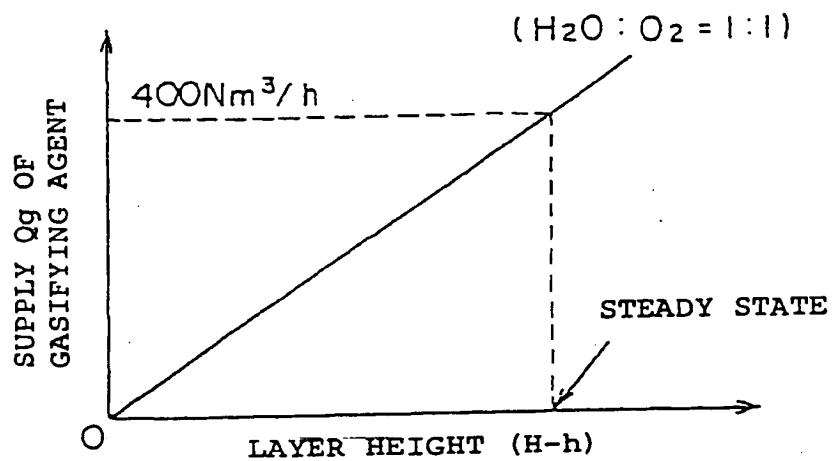


FIG. 22 (b)

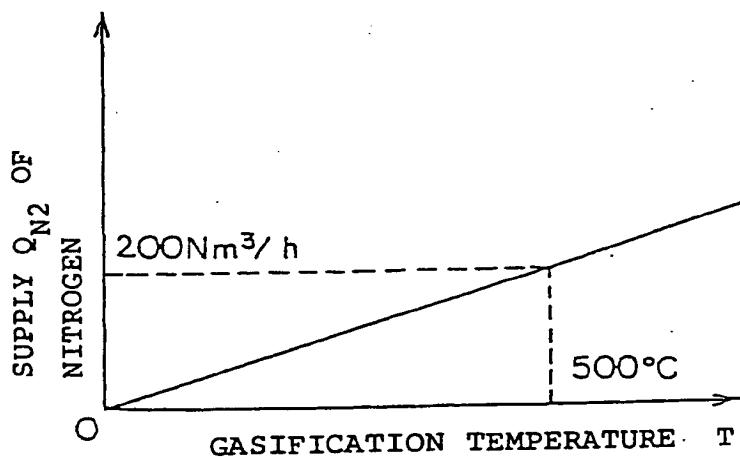


FIG. 23

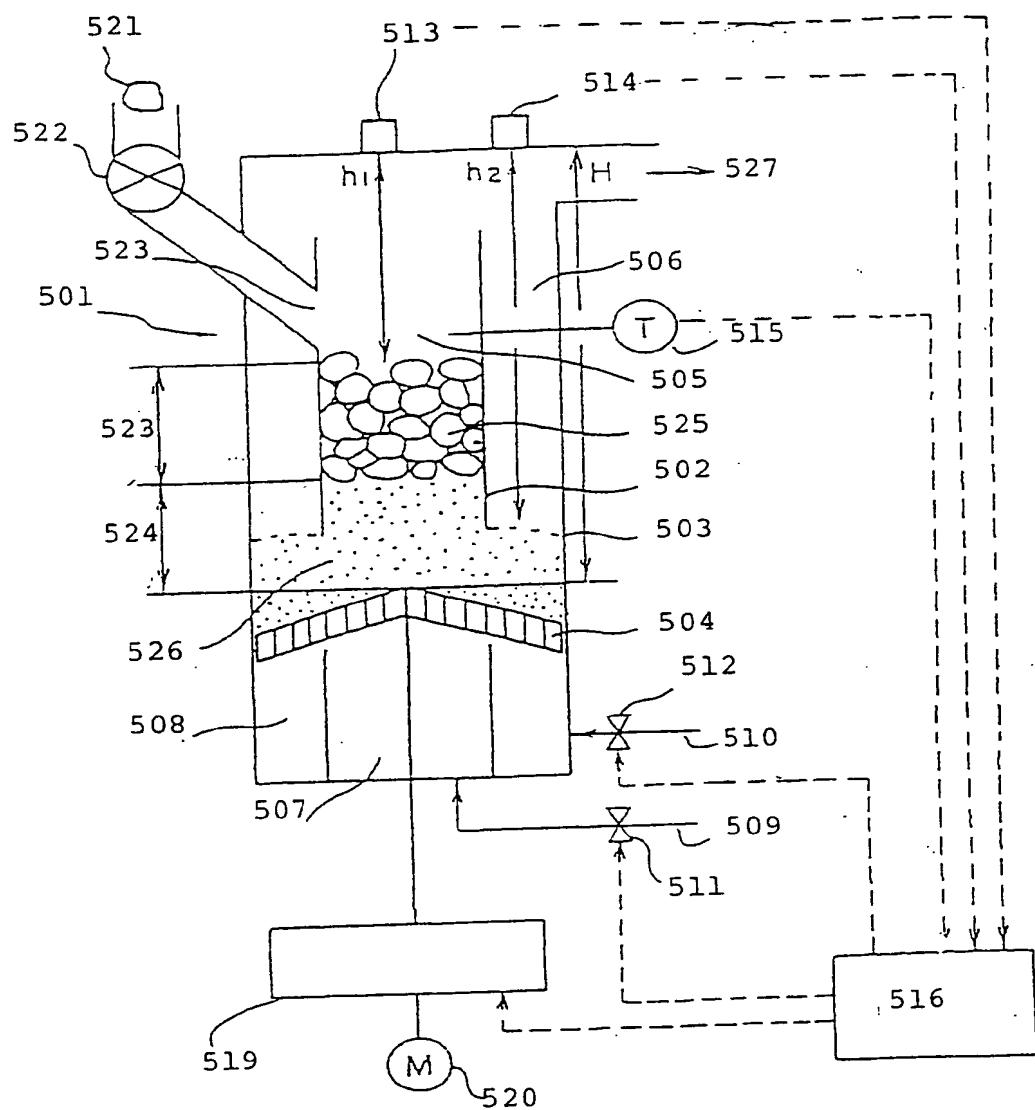


FIG. 24

PRIOR ART

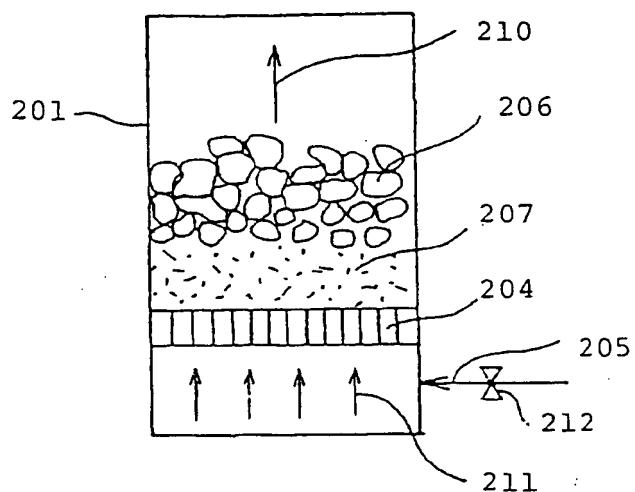
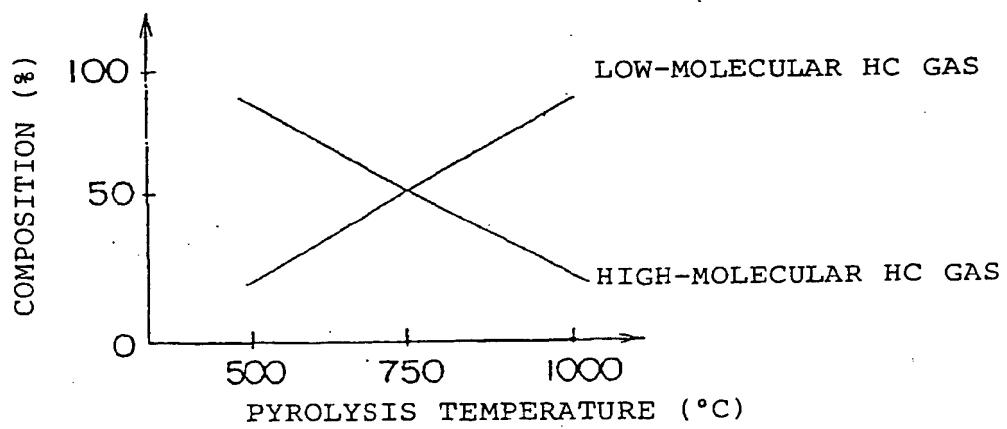


FIG. 25



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(11)

EP 0 693 539 A3

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(54) Combustion of organic wastes

(57) Method and systems for burning organic wastes such as scrap tires and waste plastics for various purposes including gasification and production of carbon black. In one aspect, a process and system for producing carbon black is disclosed. Also, the use of steam together with air or oxygen-containing gas is disclosed for combustion and/or gasification processes for scrap tires and other organic matters including plastics in fixed-bed furnaces.



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EUROPEAN SEARCH REPORT

Application Number

EP 95 11 1105

DOCUMENTS CONSIDERED TO BE RELEVANT		Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Category	Citation of document with indication, where appropriate, of relevant passages		
X	EP 0 554 688 A (RWE ENTSORGUNG) * page 2, line 24 - page 3, line 51; figure 1 *	1-3, 5	C09C1/48 C10J3/02 C10J3/58 C10J3/16
A	DATABASE WPI Week 8451 Derwent Publications Ltd., London, GB; AN 84-316400 XP002047948 & JP 59 199 772 A (HUMIMURO Y.) , 12 November 1984 * abstract *	1	
A	DATABASE WPI Week 8113 Derwent Publications Ltd., London, GB; AN 81-22825d XP002047949 & SU 747 868 A (YAROSL TECH. CARBON) , 15 July 1980 * abstract *	1	
A	US 4 171 345 A (VASSIL S. TOSHEV ET AL.) * claim 1 *	1	C09C C10J
A	DE 25 20 492 A (NAUTSCHNO-ISSLEDOWATELSKIJ INSTITUT SLANZEW ET AL.) * figure 1 *	6-14	
A	DE 26 22 266 A (PROJEKTIERUNG CHEMISCHE VERFAHRENSTECHNIK) * figure 1 *	6-14	
A	DE 38 43 926 A (METALLGESELLSCHAFT) * figure 1 *	6-14	
A	DE 37 09 225 A (METALLGESELLSCHAFT) * figure 1 *	6-14	
		-/-	
The present search report has been drawn up for all claims			
Place of search	Date of completion of the search		Examiner
THE HAGUE	24 November 1997		Van Bellingen, I
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EUROPEAN SEARCH REPORT

Application Number

EP 95 11 1105

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	GB 1 435 089 A (GENERAL ELECTRIC COMPANY) * figure 1 * ----	6-14	
A	DE 33 37 992 A (SONNENBERG H.) * figure 1 * -----	6-14	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
<p>The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	24 November 1997	Van Bellingen, I	
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X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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